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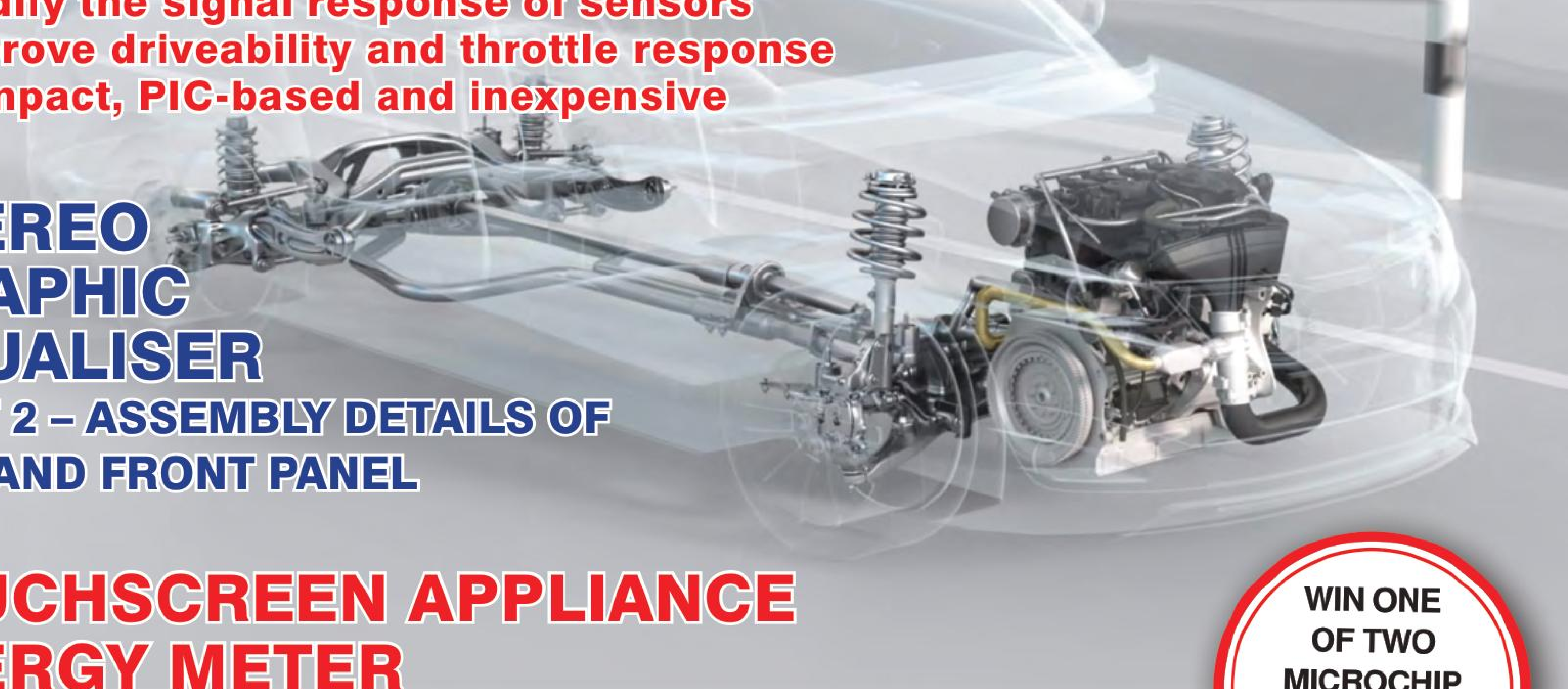

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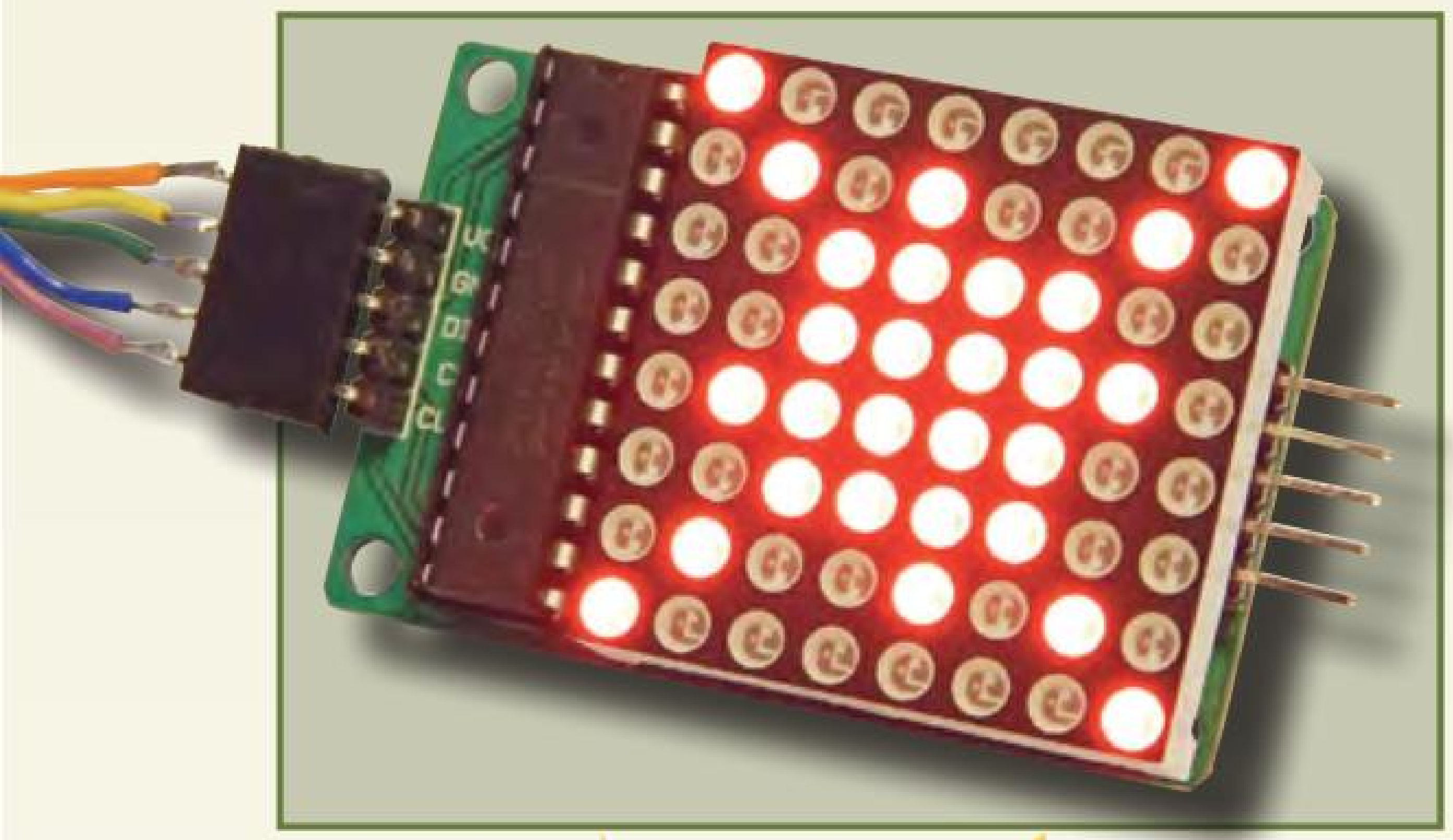

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Our August 2018 issue will be published on Thursday 5 July 2018, see page 72 for details.

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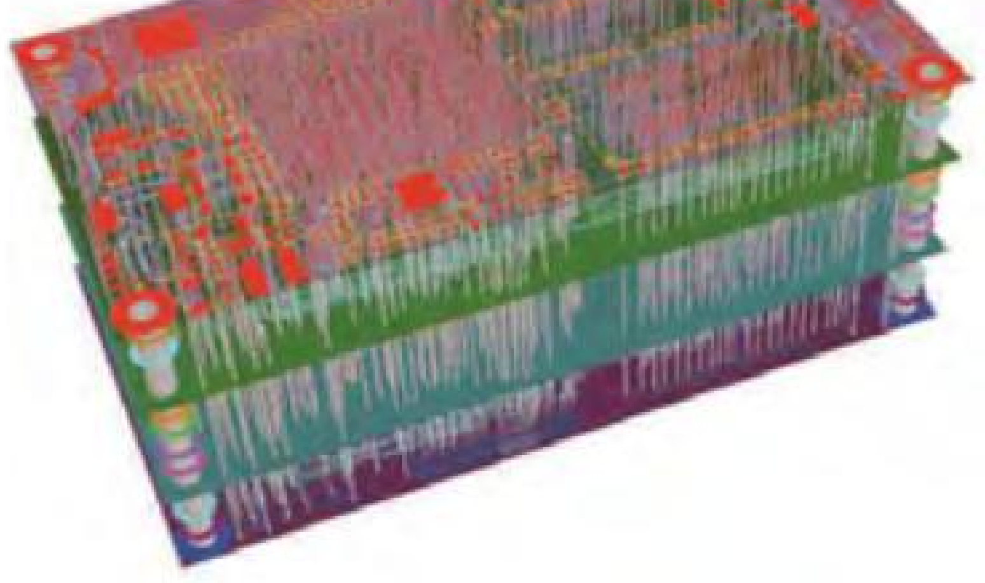

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Hello and (a temporary) goodbye

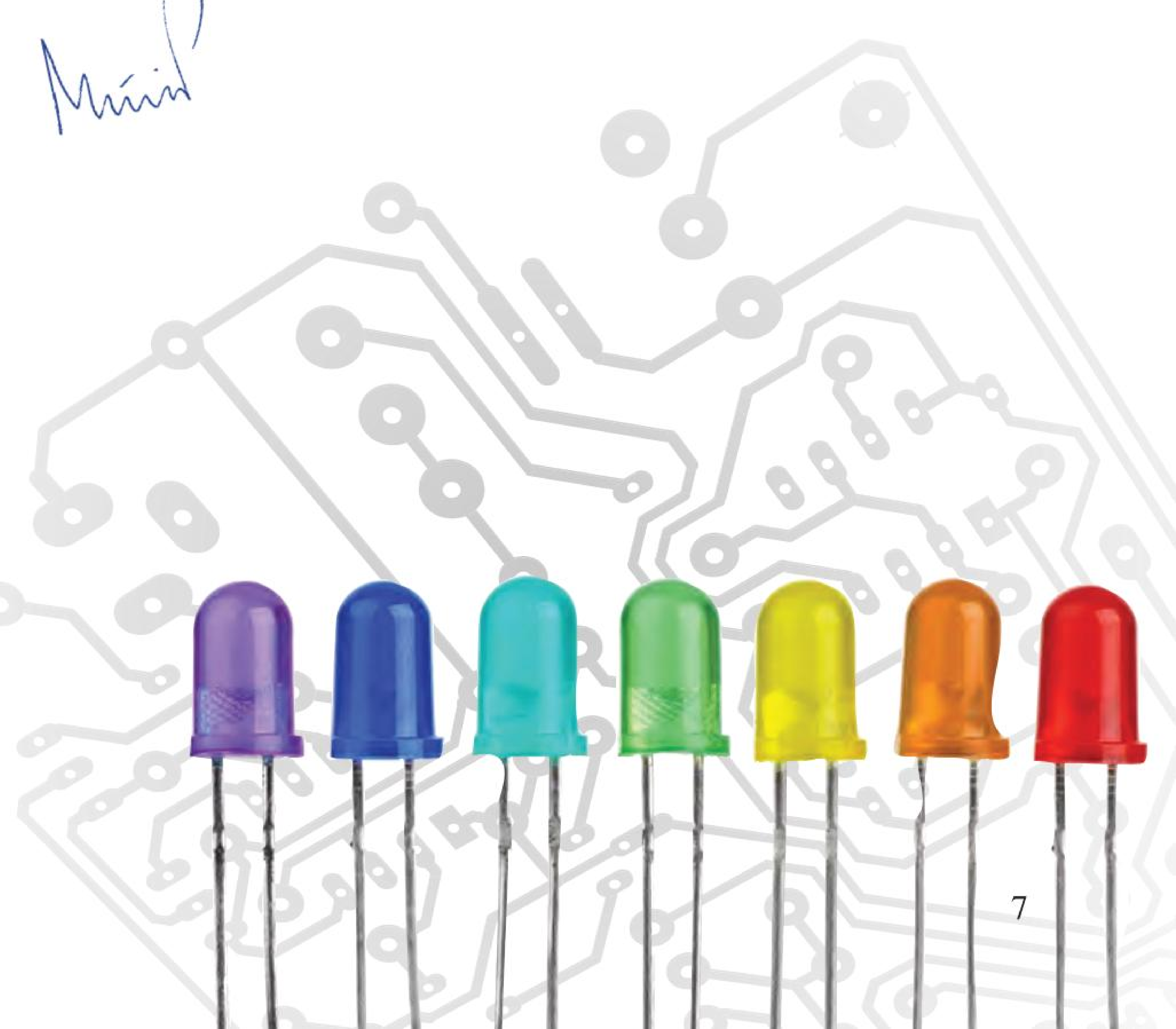
Welcome to the July issue! First, I have some columnist housekeeping, starting with a very warm welcome to a new writer for *EPE* – Dr Lucy Rogers. Lucy has a roving brief to cover all that's new and exciting in the world of electronics for hobbyists and makers. She kicks off this month with a report on 'Pi Wars', a Cambridge battle of the bots based around the ubiquitous Raspberry Pi controller board. It looks like great fun – see the video link at the end of the article – and I hope readers will be inspired to take part next year.

Next up, a (thankfully only temporary) goodbye to Mike Hibbett. When our regular *PIC n' Mix* writer Mike O'Keeffe announced that he was about to become a dad (twice over – with twins) Mike Hibbett, our former PIC columnist, very kindly offered to cover four months of much-needed paternity leave. Mike Hibbett has produced an absolutely fascinating four-part introduction to digital signal processing (DSP), which I thoroughly recommend to all *EPE* readers. Mike Hibbett is returning the baton next month, but has promised to return later this year with his own column – *Chip Select*. So, congratulations, welcome back, thank you and *au revoir* – not goodbye – to the Mikes.

Free online competitions

Each month, the generosity of a couple of corporate friends of *EPE* means that we are able to give away some PIC or Micromite-based products. While we can't match the gazillions of the National Lottery, these competitions are completely free to enter and you never know, you might just win something fun and useful. This month's Microchip's prize is their brand new PICkit 4, which just happens to be the subject of a review by Mike O'Keeffe in next month's *PIC n' Mix* column.

We thank Microchip and **micromite.org** for their ongoing support of *EPE* and its readership. This month's competitions are on pages 21 and 43 – do please enter, and the best of luck!



NEWS

A roundup of the latest Everyday News from the world of electronics

Sharp launches ambitious 8K technology – report by *Barry Fox*

The final standards for 4K UHD TV are still in flux – with HDR10, HDR10+, HLG and DolbyVision all options for High Dynamic Range display. Now Sharp, the Japanese company which has recently been through hugely complicated financial restructuring – is trying to leapfrog 4K with 8K.

Sharp chose the IFA Global Press Conference held annually in the spring – this year at a Sheraton golf resort near Rome – to promote the Berlin IFA autumn show as the Launchpad for 8K in Europe.

The buses which picked the press up from Rome airport, the bottles of water they were given, the hotel elevators and much of the welcome literature given to guests at check-in were all plastered with a common theme: 'Sharp – Be Original' with 'The World's First 8KTV'. Even the Wi-Fi password for the IFA network event was set up as 'sharp_8k'

Sharp's booth in the small exhibition area outside the briefing sessions featured a Sharp 8K screen showing 8K video material with the label 'World's First 8K Monitor'. Sharp's slogans include a logo with the letters '8K' in a golden rectangle over the text 7680 x 4320 Pixels'. The 70-inch set costs 12,000 Euros, so are unlikely to dent 4K sales.

France TV

What's more immediately interesting is how Sharp is experimenting with 8K. 'We are working with France TV on 8K' says Sascha Lange, who is in charge of marketing the set. 'We are finding out who is willing to support us with 8K. But so far we are working only with France TV.'

While in Rome, I spoke with Bernard Fontaine, Head of Tech. Innovations, at France TV:

'We want to test the system with sports' he told me. 'If you can make good pictures with sports you can make good pictures with anything, under any conditions. And tennis is the ideal sporting event. With football you have no time to change anything because the matches only last two hours. You have no time to make adjustments while people are playing. With tennis, the action is ideal for testing, a small ball moving fast is a very good test. You have time to adjust during a match.

Sharp's 8C-B60A 8K camera – yours for $77,000 (lens not included).

Viewing comparison tests

Fontaine continued, 'For *Roland-Garros* (the French equivalent of Wimbledon) we have two weeks to prepare and two weeks of play from 27 May to 10 June. *Roland-Garros* is like a laboratory. We only have one 8K camera, but we can take it anywhere inside the stadium. The tests are public – we will be inviting press, industry and VIPs. We have three rooms inside the stadium, and one of them looks out onto the court so people will be able to look at the match live and on screen.

'We will be comparing HEVC (H265) 8K compression with uncompressed 8K signals, and comparing 4K with 8K. We are hoping we will be able to bypass the compression which happens inside the Sharp 8K camera, to work with completely uncompressed signals.

'We would like to work with NHK on this but we can't because of TV rights issues. The way France TV is funded we can do the *Roland-Garros* tests for a month and not need to earn anything from selling or broadcasting anything. It's a public test, with shared information. The way NHK is funded is different and they would want to own the material and broadcast some of it by satellite. So they can't have cameras inside *Roland-Garros*.

8K in the UK?

'The way the BBC is funded is more like France TV, so we would like to collaborate – however, nothing is yet agreed and we are not yet working with the BBC. But we would love to do tests at Wimbledon. Sky is another candidate. You can't make television alone.'

I asked the BBC for comment but got no response.

Show wars – Berlin vs Las Vegas

While in Rome, Dr Christian Göke, CEO of Messe Berlin, the organisation which stages the IFA show in Berlin, renewed his war of words with the show's great rival, CES in Las Vegas.

Göke reeled off statistics to prove that 2017 had been a 'record year' with 252,000 people visiting the Berlin exhibition halls, of which 145,000 were trade visitors from 121 countries. He said 1800 brands were on show in 240,000m^2 of floor space, 'which is equivalent to 12 Rome Coliseums'.

'This IFA show is literally covering the world,' Göke said. 'This show is undisputedly the number one consumer electronics show. Yes, there are other tech events in the US, and they are formally known as 'CE shows', but let's be honest, it's not always that easy to understand how these shows are structured.'

Alluding to the power cut which blighted CES in January 2017, he teased: 'Sometimes it's not that easy to go from hall to hall and hotel to hotel, even when the lights are on. For brands, it's always a bit of a *gamble* as to whether or not you'll make your mark there – which is fitting, given the location (Las Vegas).'

During the Q&A session Göke was asked by a US journalist why he denigrated CES, to promote IFA, when IFA and CES are very different shows, serving different purposes with different audiences. Göke responded: 'There was no denigration intended at all'.

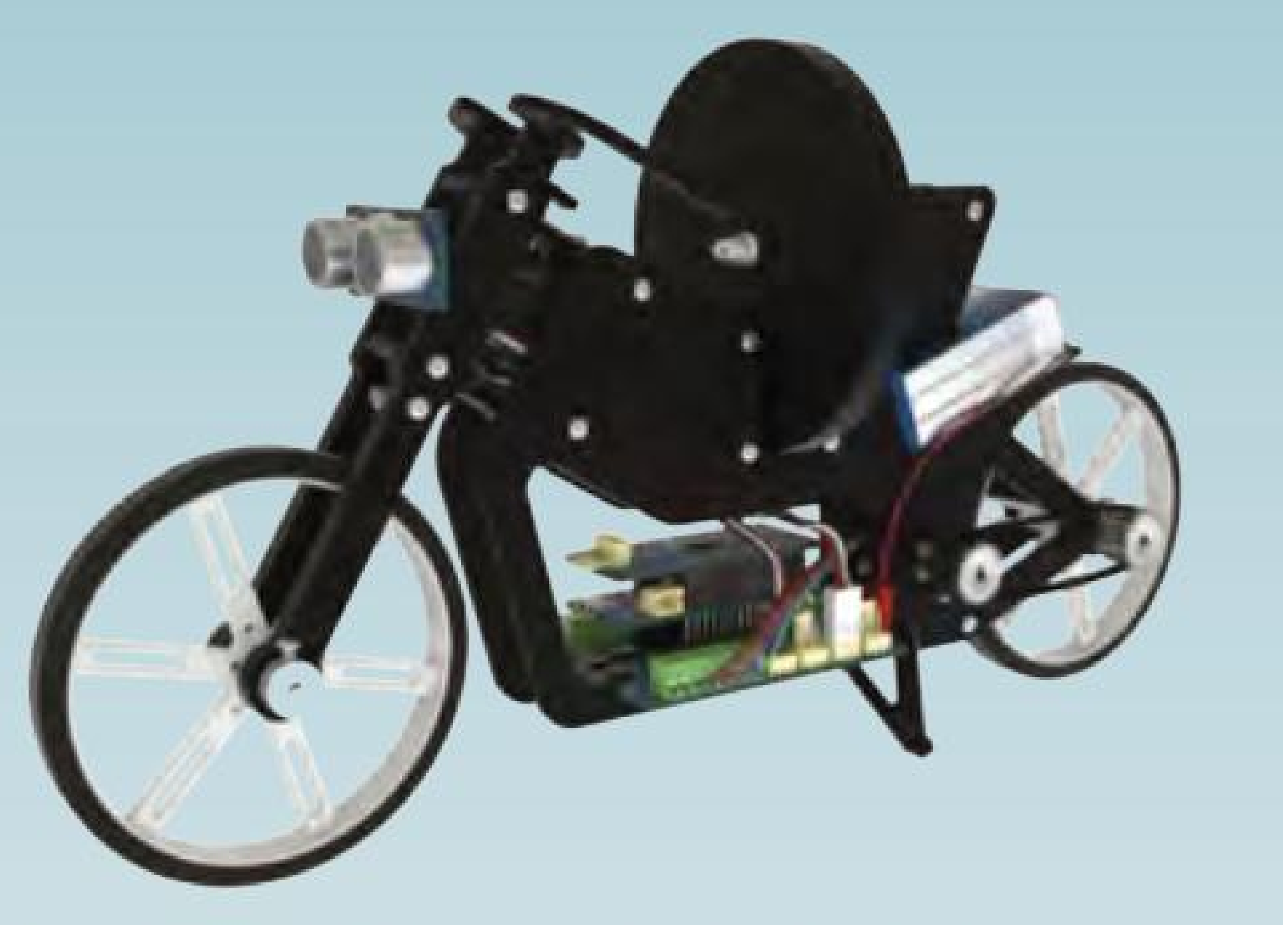
Anyone who has visited IFA in Berlin will know how difficult it is to navigate the many halls and find company booths. So I asked whether IFA had considered an easier booth signage system, like the New York street grid layout, with high ceiling mount signs for Lane A, B, C crossing Row 1, 2, 3 and so on. Had the IFA organisers ever given a real person a booth number and watched how long it took them to find it?

IFA
Fast Forward To The Future!
The World's First 8K TV
8K
SHARP
Be Original.

Sharp – determined not to miss the 8K bus branded their own at the IFA Global Press Conference 2018.

Göke argued that exhibitors would not like a monotonous rectangular booth layout. Jens Heithecker, IFA executive director, said if people got lost looking for one booth they would find others by chance. When the assembled press laughed at this, Göke said quickly that of course Heithecker was only joking. One journalist compared getting round IFA to visiting IKEA, where disorientated customers buy what they never knew they wanted or needed.

Arduino Engineering Kit



Build a self-balancing bike with Arduino's new Engineering Kit

Arduino has a new partnership with MathWorks, a leading developer of mathematical computing software for engineers and scientists, to promote Arduino at the university level in the fields of engineering, Internet of Things, and robotics.

The Arduino Engineering Kit is the first product released as a result of this partnership. The Kit consists of three cutting-edge, Arduino-based projects that teach students how to build modern electronic devices:

- Self-Balancing Motorcycle: This motorcycle will move on its own on various terrains and remain upright using a flywheel for balance.
- Mobile Rover: This vehicle can navigate between given reference points, move objects with a forklift, and much more.
- Whiteboard Drawing Robot: This robot can take a drawing it's given and replicate it on a whiteboard.

In addition to the hardware included, students will have access to a dedicated e-learning platform and other learning materials. Additionally, they are granted a one-year individual license for MATLAB and Simulink, which provides them with hands-on experience in system modeling and embedded algorithm development. Further details are available at: **https://store.arduino.cc/arduino-engineering-kit**

Amazing drones!

As drones get smaller and smaller – approaching true insect size – the key problem is power. Milligram devices can't get take off with a couple of AAs strapped to their bodies. Sawyer Fuller at the University of Washington has taken the next step by pointing a laser at an on-board solar cell. More details at: **https://faculty.washington.edu/minsterPicoScope**

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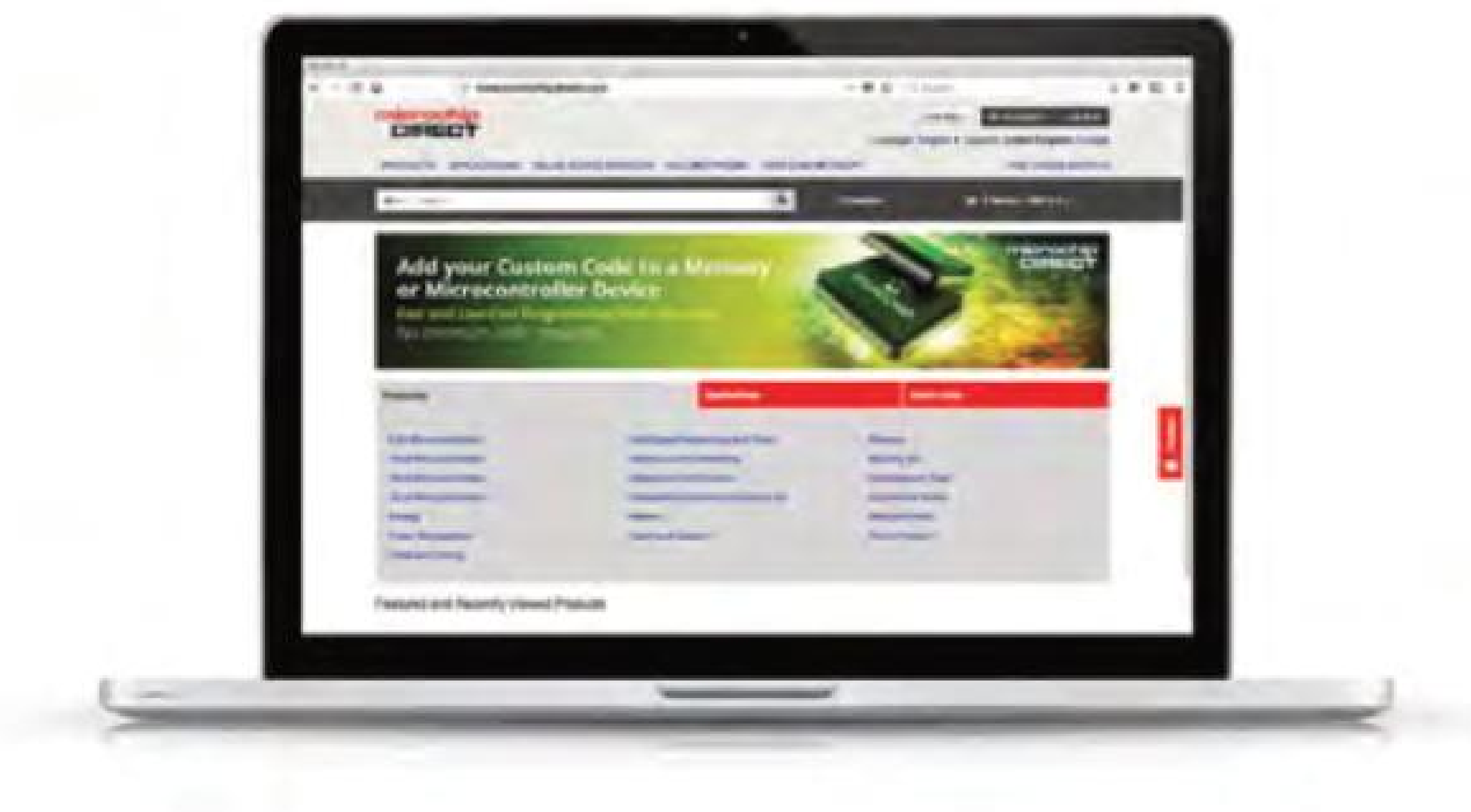

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Wetter, better batteries

TechnoTalk

Mark Nelson

Despite the current major emphasis on lithium and other types of solid batteries, researchers are still investigating cells that use liquid electrolytes. Consumer electronics could exploit one of these developments, while another holds great promise for implanting batteries within the soft-tissue regions of the human body.

THE PRESSURE TO DEVELOP more efficient means of creating and storing electrical energy shows no signs of flagging. A better battery, delivering greater energy density (energy per unit volume), using readily available raw materials and assuring zero harm to users is the goal. Thinking laterally, scientists are looking to nature for inspiration, and specifically at electric eels (botanical name *Electrophorus electricus*). These fascinating creatures, which grow up to 2.5m in length and 20kg in weight, inhabit the fresh waters of the Amazon and Orinoco river basins in South America, generally in floodplains, swamps, small rivers, and coastal plains. You can also find them at the Tennessee Aquarium in the US, home to an electric eel that uses its own electrical discharges to tweet from its own Twitter account. Named 'Miguel Wattson', the eel's aquarium is connected to a small computer that sends out a prewritten message when Miguel emits electricity at a sufficiently high threshold – see: **https://twitter.com/EelectricMiguel** –for example: 'I like to approach life like a battery and embrace both the positive and the negative'!

Shock development

Nobody has suggested eel farming as a source of power storage, and it would hardly be ethical. In any case, although a mature eel can produce a shock of up to 860V at one amp, it can keep this up for only a couple of milliseconds or so. But a battery technology that mimics the way eels generate power is being developed for medical use. Scientists at the University of Fribourg in Switzerland have taken inspiration from the electric eel to create a flexible, transparent electrical device that could lead to body-friendly power sources for implanted health monitors and medication dispensers, augmented-reality contact lenses and countless other applications.

'The eel polarises and depolarises thousands of cells instantaneously to put out these high voltages,' says collaborator Prof Max Shtein. 'It's a fascinating system to look at from an engineering perspective – its performance metrics, its fundamental building blocks and how to use them.'

One secret to the eel's success is a phenomenon called 'transmembrane transport'. Specialised electrical organs contain thousands of alternating compartments, each with an excess of either potassium or sodium ions. The compartments are separated by selective membranes that, in the eel's resting state, keep the two ions separate. When the eel needs to create a jolt of electricity, the membranes allow the ions to flow together, thus releasing a burst of power.

Mimicking nature

The researchers built an energy storage system similar to the eel's, using sodium and chloride (the constituents of common table salt) dissolved in water-based hydrogel. Using a specialised printer at the Adolphe Merkle Institute, they printed thousands of tiny droplets of the salty gel on a plastic sheet, alternating them with hydrogel droplets of pure water. The alternating droplets are similar to the eel's compartmented cells. The team's device forms the first potentially biocompatible artificial electric organ that generates more than 100V. It produces a steady buzz of electricity at high voltage but low current, a bit like an extremely low-volume but high-pressure jet of water. This is perhaps enough to power a small medical device like a pacemaker.

Another watery tale

Everyone knows that so-called 'dry' batteries are not really dry. Inside them is a paste containing an electrolyte that can ruin electronic devices if the liquid leaks out. Now a team of researchers at the University of Maryland (US) has devised a new water-based aqueous electrolyte that gives zinc batteries far greater power density and eliminates many of their current drawbacks. The result is a water-based zinc battery that is simultaneously powerful, rechargeable, and intrinsically safe.

'Water-based batteries could be crucial to preventing fires in electronics, but their energy storage and capacity have been limited – until now. For the first time, we have a battery that could compete with the lithium-ion batteries in energy density, but without the risk of explosion or fire,' says Fei Wang, a postdoctoral associate. He says the new aqueous zinc battery could eventually be used not just in consumer electronics, but also in extreme conditions to improve the performance of safety-critical vehicles, such as those used in aerospace, military, and deep-ocean environments.

As an example of the aqueous zinc battery's power and safety, Fei Wang cites the numerous battery fire incidents in cell phones, laptops, and electric cars highlighted in recent media coverage. The new battery could be the answer to the call for safe battery chemistry, while offering similar or even higher energy densities compared to conventional lithium-ion batteries.

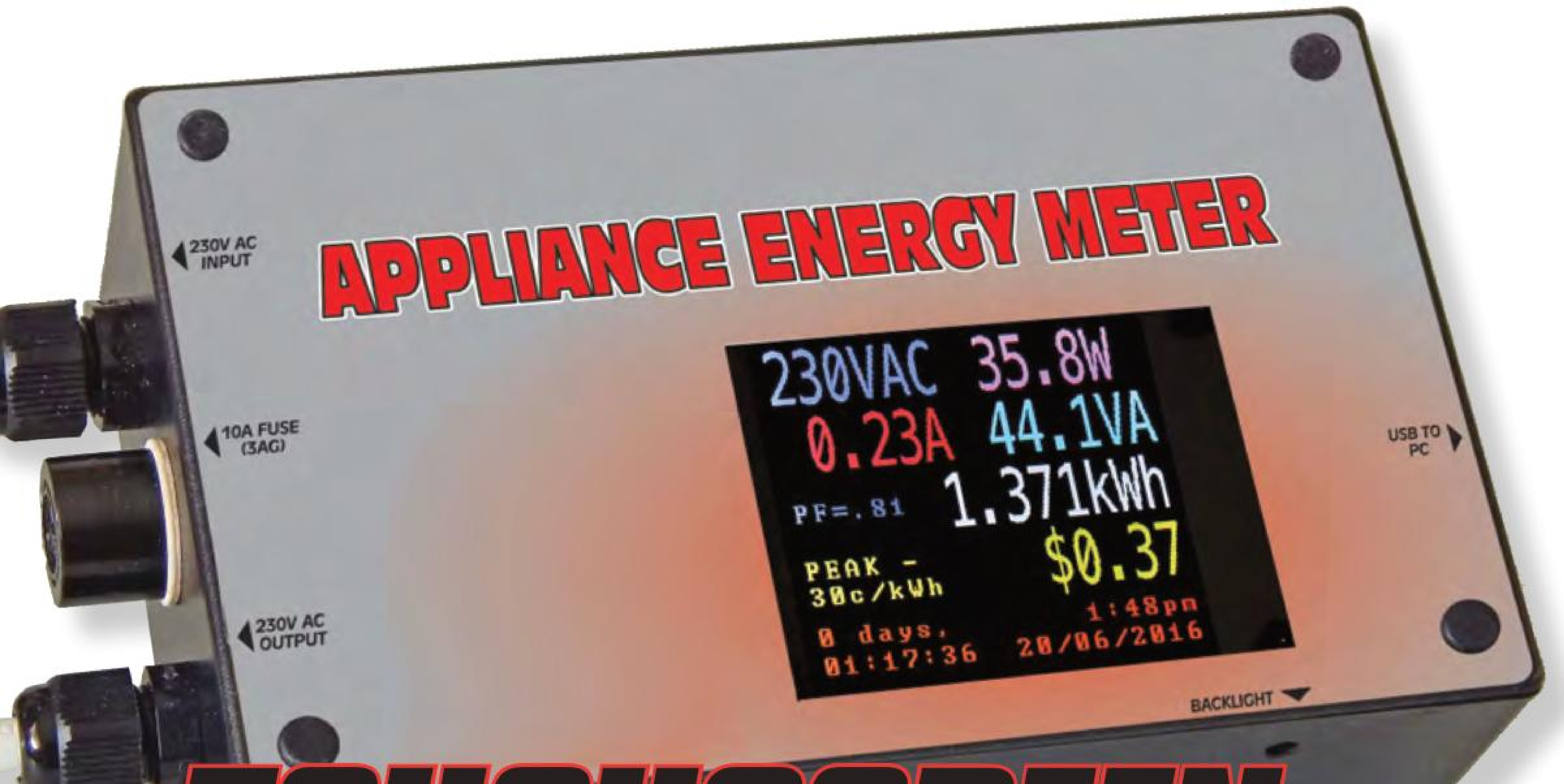
Perfecting the zinc battery

This highly concentrated aqueous zinc battery also overcomes other disadvantages of conventional zinc batteries, such as the capacity to endure only limited recharging cycles, dendrite (tree-like structures of crystals) growth during usage and recharging, and sustained water consumption, resulting in the need to regularly replenishing a battery's electrolyte with water.

'Existing zinc batteries are safe and relatively inexpensive to produce, but they aren't perfect due to poor cycle life and low energy density,' says Chunsheng Wang, professor of chemical and biomolecular engineering. He explains that zinc batteries also suffer from the need for sustained water consumption, something that the new approach eliminates by using a highly concentrated electrolyte.

'Because most water molecules in the new electrolyte are strongly bonded by the highly concentrated salt, the water in the aqueous zinc battery's electrolyte will not evaporate in an open cell. This advance revolutionises zinc-air batteries, which are powered by oxidising zinc with oxygen from the air, such as those used in energy grid storage,' he adds.

By creating a highly rechargeable zinc battery, this development could offer a low-cost, safe alternative for consumer electronics, cars and electrical grid storage. The team says this battery technology advance lays the groundwork for further research, and they are hopeful for possible future commercialisation.



Part 1

By JIM ROWE and NICHOLAS VINEN

- Full-colour touchscreen for easy operation
- Measures mains voltage, current, real power, VA, kilowatt-hours and running cost
- Allows for time-of-day tariffs: peak/shoulder/off-peak
- Displays graphs of power use over time
- Logged data can be downloaded to a PC

TOUCHSCREEN APPLIANCE ENERGY METER – PART 1

How much do your appliances actually cost to run? Are you getting the most bang for your buck? This new *Appliance Energy Meter* will tell you exactly how much they're using, how much they're costing you and the total energy consumed. It can even log the results to your computer.

This completely new design measures the mains voltage and the appliance's load current, then multiplies the two (taking into account the power factor, including any phase difference) to work out the power being used. Then it integrates this over time to determine the total energy usage in kWh (kilowatt-hours). At the same time, it multiplies the power consumption by the energy tariff that is applicable at the time (ie, peak/off-peak) and keeps a running total of the energy cost over time.

It displays all this (and much more information) in an easy-to-understand form via its colour LCD screen. There are no switches or knobs to operate since all control is done via the colour LCD touchscreen, which works like the touchscreen on your smartphone. It is based on the *Micromite BackPack* module plus a matching 2.8-inch LCD touchscreen module (as described in the May 2017 issue).

One obvious use for this unit is to show refrigerator or air conditioner running costs over a set period of time, so that you can quickly determine the effect of different thermostat settings. Alternatively, it could be used to show the difference in energy consumption between the summer months and the winter months.

If you have a solar power installation, the *Appliance Energy Meter* will quickly allow you to determine which appliances are the most 'power hungry', so that you can adjust your energy usage patterns to suit the time of day when solar power is available. This will maximise the benefit of your solar panels. For example, by running your pool pump, dishwasher, washing machine or air conditioner during the day from your solar panels, your energy cost for running these appliances will essentially be zero.

That's a much better result than merely accepting the solar feed-in tariff of a few pennies per kilowatt-hour.

Standby power

The cost of standby power is something that most people never think about. There are lots of appliances in your home that continuously consume power, 24 hours a day, even when they are supposedly 'switched off', especially via a remote control. These appliances include TV sets, DVD players, Hi-Fi equipment and cable and satellite TV receivers.

Then there are those devices that are powered via a plugpack supply: modems, some printers, portable CD players and battery chargers (eg, for mobile telephones) and so on. Most continue to draw power even though the device itself might be off. But how much power? This *Appliance Energy Meter* will tell you.

Many high-power appliances also continue to draw current when they are not being used. These could include your microwave oven, wall oven, dishwasher, washing machine and air-conditioners. Typically, the standby power usage for each of these appliances is about 2W but some are significantly higher.

Then there are those appliances which must always be on, otherwise there's no point having them; for example, cordless telephones, digital alarm clocks, burglar alarms and garage door openers.

Do a quick audit of your house – you may be quite surprised at how many appliances you have that are either permanently powered or operating on standby power. By using the *Appliance Energy Meter*, you can quickly monitor these devices and find out which are the energy wasters

Specifications

• Measures mains voltage, appliance current and time	
• Voltage resolution (rounded for display)	0.1V
• Maximum measured current	20A (100A surge)
• Appliance current resolution	0.01A
• Maximum volt-amps reading	5100VA
• Maximum wattage (real power) reading	5100W
• Wattage resolution	0.1W
• Uncalibrated error	typically <3%
• Calibrated error	typically <1%
• Sampling rate	~5kHz
• Timing clock accuracy	<10ppm
• Logging interval	1, 10 or 60 seconds
• Maximum logging duration	7 days (60s interval)
• Cost resolution	0.001c/kWh

and decide which can be updated or simply turned off at the wall if they don't need to run continuously.

What about cheap power consumption meters?

Of course, we are aware that there are plenty of power consumption meters available on-line for around £15 to £30, which can monitor appliances. But they're not a patch on this one! Our experience is that their LCDs are often hard to read/decipher and they lack colour or any graphics capability. Nor do they have touchscreens. Plus, we've seen two side-by-side reading quite differently on the same load!

The more expensive 'wireless' models (which have a transmitter in the fuse box and a display inside) are actually quite limited in what they can show you – for example, they cannot show individual appliance power, nor can they show true energy costs (they don't know the difference between time of day tariffs so work on 'worst case'). They can read current, but assume a certain voltage, so they can't accurately calculate power.

By contrast, the readings on our new *Appliance Energy Meter* are far more legible, with bright colours. It also offers immediate switching between screens to show energy usage or cost over time with time-of-day tariffs taken into account.

Plus, this information can be displayed as graphs over time or as histograms (bargraphs) so you can quickly assess how power consumption varies as appliances cycle on and off.

Or you can see how power consumption varies over the full cycle of a washing machine or dishwasher. Say you have a washing machine that heats its own water electrically (as many UK models do). Do you really need to use that hot/hot setting or will a cooler (or even cold) setting save you money? This will tell you – and you might be in for a real surprise!

Using the Appliance Energy Meter

As shown in the photos, the new *Appliance Energy Meter* is housed in a compact plastic box with the touchscreen on the top panel. It has two 250VAC 10A mains leads – one with a 3-pin plug, to supply power from the mains and the other with a 3-pin socket, to supply power to the appliance.

The unit is easy to use; simply plug it into the mains socket and plug the appliance into the output lead. Turn the power on and it will immediately show the main screen with the following information:

- Mains voltage (eg, 237VAC)
- Mains current (eg, 2.25A)
- Mains frequency (eg, 50Hz)
- Real power (eg, 475W)
- VA (eg, 533VA)
- Power factor (eg, 0.89)
- Duration (elapsed time)
- Running total (in kWh)
- Current tariff (peak, shoulder or off-peak)
- Running total cost
- Current time and date

Note that if you don't have a smart meter in your home, you may only have a single tariff which applies all the time. In this case, you can leave the peak and 'shoulder' periods blank and the unit will compute cost using just one tariff.

PCB design

Most of the circuitry for the *Appliance Energy Meter* is accommodated on a single, large, double-sided PCB. The *Micromite BackPack* and 2.8-inch touchscreen are attached

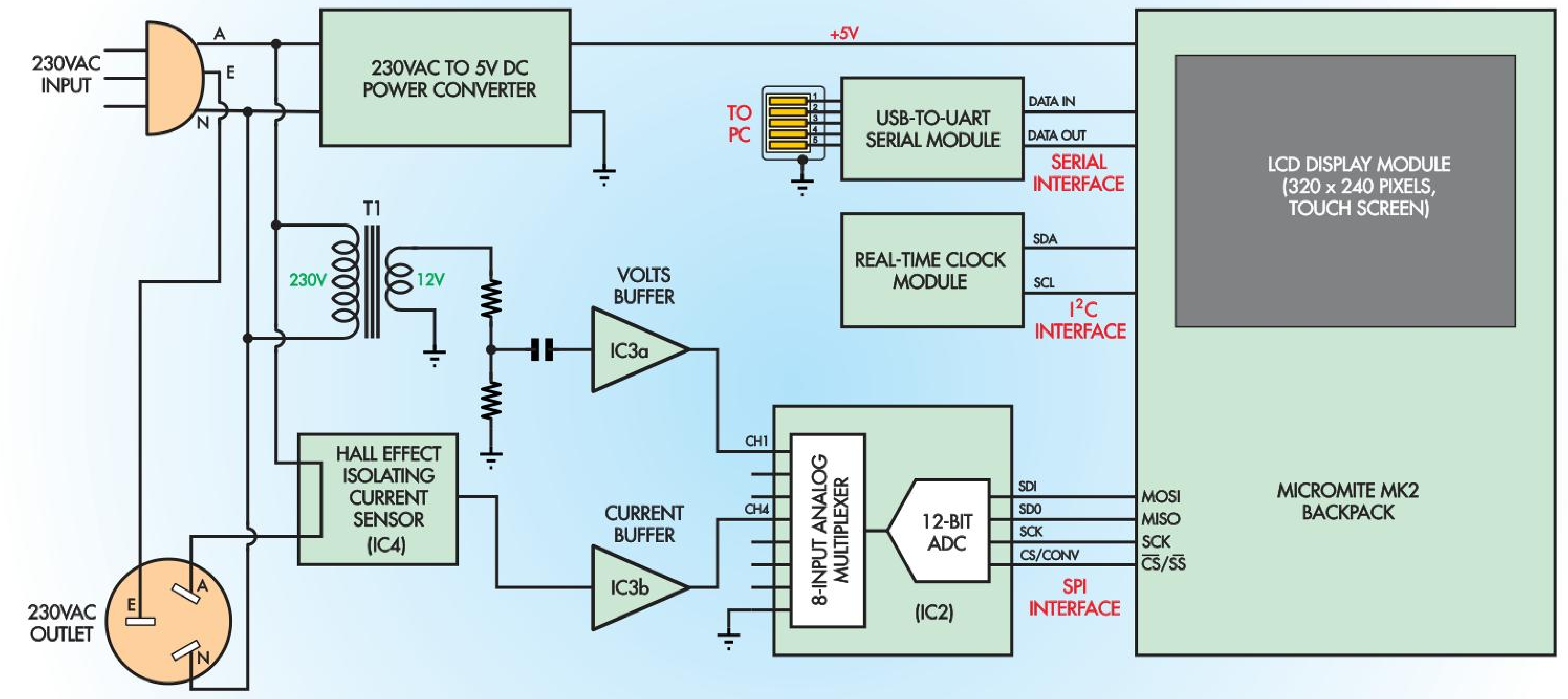
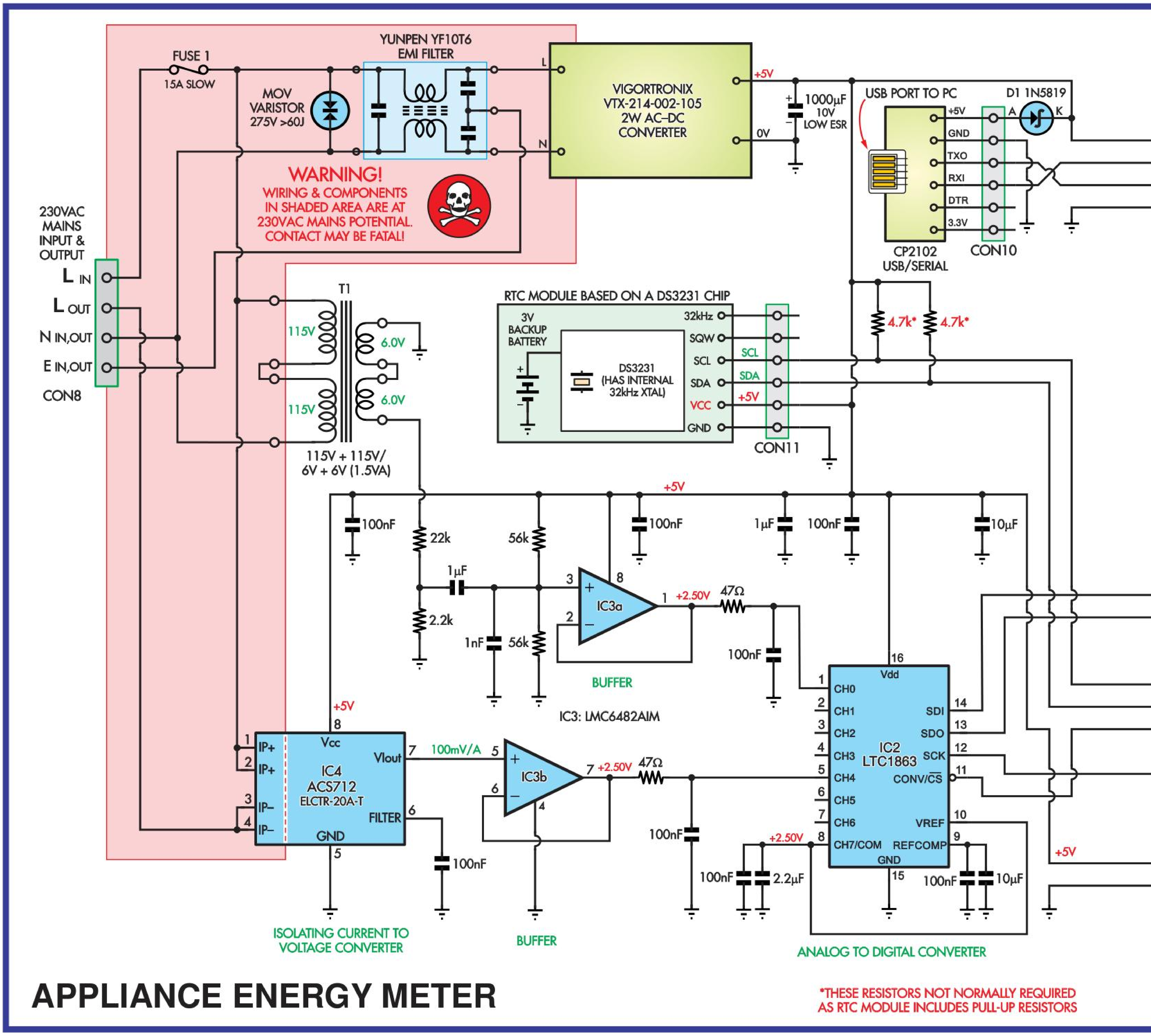

230VAC INPUT
A
E
N
230VAC TO 5V DC POWER CONVERTER
+5V
TO PC
1
2
3
4
5
6
USB-TO-UART SERIAL MODULE
DATA IN
DATA OUT
SERIAL INTERFACE
LCD DISPLAY MODULE (320 x 240 PIXELS, TOUCH SCREEN)
T1
230V
12V
VOLTS BUFFER
IC3a
REAL-TIME CLOCK MODULE
SDA
SCL
I²C INTERFACE
HALL EFFECT ISOLATING CURRENT SENSOR (IC4)
CURRENT BUFFER
IC3b
CH1
CH4
8-INPUT ANALOG MULTIPLEXER
12-BIT ADC
(IC2)
SDI
SD0
SCK
CS/CONV
SPI INTERFACE
MOSI
MISO
SCK
CS/SS
MICROMITE MK2 BACKPACK
230VAC OUTLET
E
A
N

Fig.1: block diagram of the *Energy Meter*. T1 provides a voltage proportional to the mains, while IC4's output indicates the load current. The Micromite reads both via analogue-to-digital converter IC2 and displays the readings on its LCD.


FUSE 1
15A SLOW
MOV VARISTOR 275V >60J
YUNPEN YF10T6 EMI FILTER
VIGORTRONIX VTX-214-002-105 2W AC–DC CONVERTER
L
N
+5V
0V
1000µF 10V LOW ESR
USB PORT TO PC
D1 1N5819
A
K
+5V
GND
TXO
RXI
DTR
3.3V
CP2102 USB/SERIAL
CON10
WARNING!
WIRING & COMPONENTS IN SHADED AREA ARE AT 230VAC MAINS POTENTIAL. CONTACT MAY BE FATAL!
230VAC MAINS INPUT & OUTPUT
L IN
L OUT
N IN,OUT
E IN,OUT
CON8
T1
115V
115V
6.0V
6.0V
115V + 115V/ 6V + 6V (1.5VA)
RTC MODULE BASED ON A DS3231 CHIP
3V BACKUP BATTERY
DS3231 (HAS INTERNAL 32kHz XTAL)
32kHz
SQW
SCL
SDA
VCC
GND
SCL
SDA
+5V
CON11
4.7k*
4.7k*
+5V
100nF
22k
56k
100nF
1µF
100nF
10µF
1µF
2.2k
1nF
56k
IC3a
BUFFER
+2.50V
47Ω
100nF
IC3: LMC6482AIM
+5V
IC4 ACS712 ELCTR-20A-T
IP+
IP+
IP–
IP–
Vcc
Viout
FILTER
GND
100mV/A
100nF
IC3b
+2.50V
47Ω
100nF
ISOLATING CURRENT TO VOLTAGE CONVERTER
BUFFER
IC2 LTC1863
Vdd
CH0
CH1
CH2
CH3
CH4
CH5
CH6
CH7/COM
SDI
SDO
SCK
CONV/CS
VREF
REFCOMP
GND
+2.50V
100nF
2.2µF
100nF
10µF
+5V
ANALOG TO DIGITAL CONVERTER

APPLIANCE ENERGY METER

*THESE RESISTORS NOT NORMALLY REQUIRED AS RTC MODULE INCLUDES PULL-UP RESISTORS

to the lid and wired to the main PCB via a ribbon cable with IDC connectors.

Components on the board include an EMI filter, a 230VAC to 6V+6V transformer (T1), a 230VAC to 5V DC switch-mode converter, a precision real-time clock and a USB-to-UART serial converter, for both programming and logging. There are also special purpose ICs for an isolating current-to-voltage converter (IC4) and an analogue-to-digital converter (ADC) – IC2.

How it works

As well as measuring mains voltage and appliance current, the *Appliance Energy Meter* performs a lot of calculations and these are detailed in a separate panel.

Let's now look at the block diagram of Fig.1 which shows the overall configuration of the new *Appliance Energy Meter*. The heart of the meter is the already-mentioned Micromite Mk2 BackPack with its 320 × 240 pixel colour LCD touch screen, shown at the right-hand side.

At upper left you can see the 230VAC mains input, used to provide power for the meter itself, as well as for the appliance connected to the 230VAC outlet at lower left.

The two parameters that the meter needs to measure in order to determine the energy consumption of an appliance are the mains voltage and the current being drawn by the appliance.

To measure the mains voltage safely, we use a tiny step-down transformer (T1) to provide isolation. This delivers a secondary AC voltage of 12V RMS (= 33.93V peak-to-peak) when the mains voltage is 230VAC.

As this is too high for our measurement circuitry, we use a resistive voltage divider to reduce it further. Then the divided-down mains voltage signal is fed through a unity gain buffer amplifier, IC3a. The relationship between this voltage and the mains voltage is calibrated via the software.

To measure the appliance current, we use an Allegro ACS712-x20A isolating linear current sensor, IC4. This provides linear current sensing over a range ±20A, with an input-output isolation of better than 2.1kV RMS or 5.9kV peak-to-peak.

The appliance current passes through a very-low-resistance 'loop' on one side of the device, while on the other side, a linear Hall effect circuit senses the magnetic field around the loop and provides an output voltage proportional to the instantaneous loop current. The output voltage is specified as 100mV/A, linear over a ±20A range.

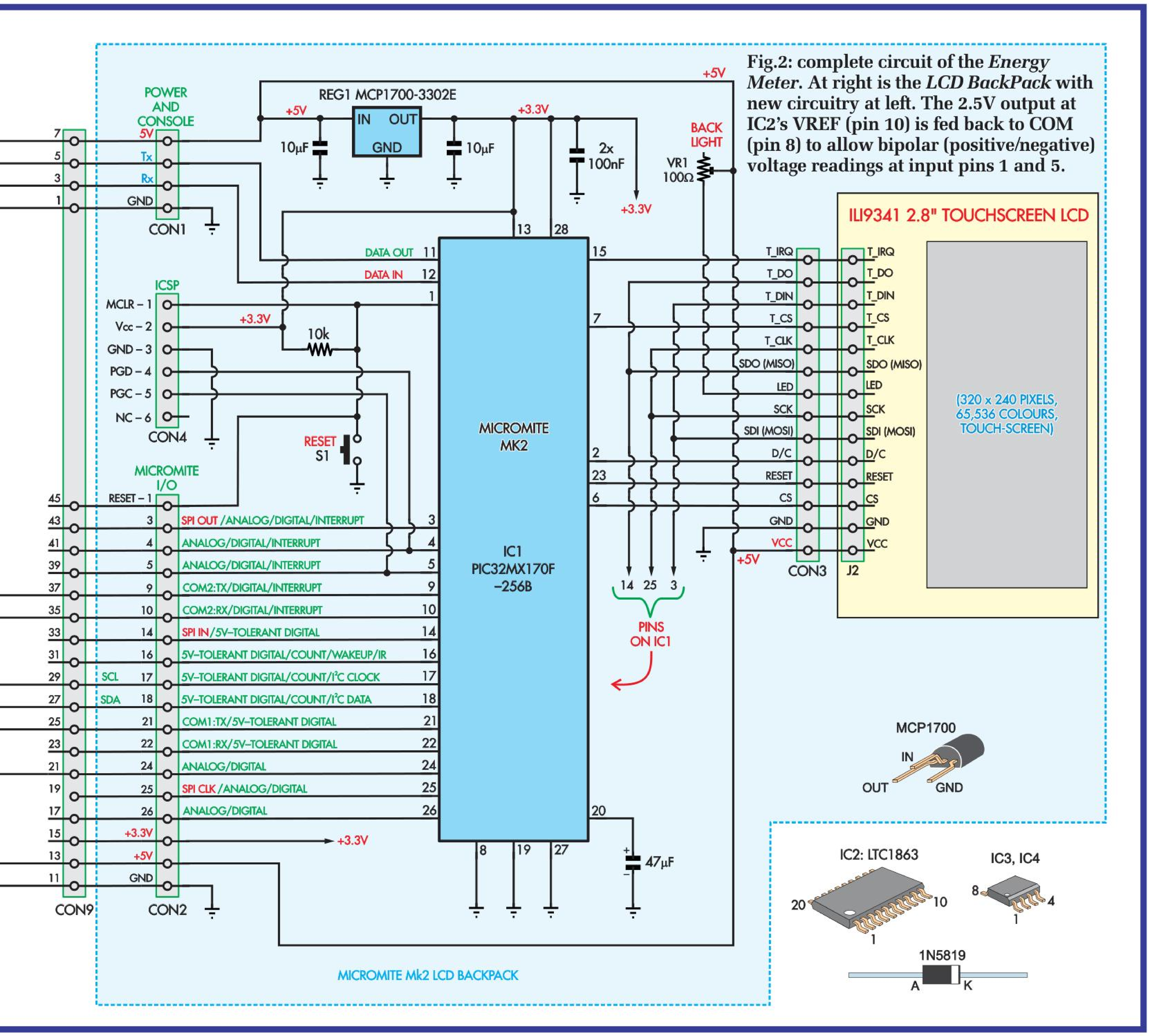

POWER AND CONSOLE
5V
Tx
Rx
GND
CON1
REG1 MCP1700-3302E
+5V
IN
OUT
GND
10μF
10μF
+3.3V
2x 100nF
+3.3V
+5V
BACK LIGHT
VR1 100Ω
ICSP
MCLR – 1
Vcc – 2
GND – 3
PGD – 4
PGC – 5
NC – 6
CON4
+3.3V
10k
RESET S1
MICROMITE I/O
RESET – 1
SPI OUT /ANALOG/DIGITAL/INTERRUPT
ANALOG/DIGITAL/INTERRUPT
ANALOG/DIGITAL/INTERRUPT
COM2:TX/DIGITAL/INTERRUPT
COM2:RX/DIGITAL/INTERRUPT
SPI IN/5V–TOLERANT DIGITAL
5V–TOLERANT DIGITAL/COUNT/WAKEUP/IR
SCL
5V–TOLERANT DIGITAL/COUNT/I²C CLOCK
SDA
5V–TOLERANT DIGITAL/COUNT/I²C DATA
COM1:TX/5V–TOLERANT DIGITAL
COM1:RX/5V–TOLERANT DIGITAL
ANALOG/DIGITAL
SPI CLK /ANALOG/DIGITAL
ANALOG/DIGITAL
+3.3V
+5V
GND
CON9
CON2
+3.3V
DATA OUT
DATA IN
MICROMITE MK2
IC1 PIC32MX170F –256B
47μF
14 25 3
PINS ON IC1
T_IRQ
T_DO
T_DIN
T_CS
T_CLK
SDO (MISO)
LED
SCK
SDI (MOSI)
D/C
RESET
CS
GND
VCC
+5V
CON3
J2
ILI9341 2.8" TOUCHSCREEN LCD
(320 x 240 PIXELS, 65,536 COLOURS, TOUCH-SCREEN)
MCP1700
IN
OUT
GND
IC2: LTC1863
IC3, IC4
1N5819
A
K
MICROMITE Mk2 LCD BACKPACK

Fig.2: complete circuit of the *Energy Meter*. At right is the *LCD BackPack* with new circuitry at left. The 2.5V output at IC2's VREF (pin 10) is fed back to COM (pin 8) to allow bipolar (positive/negative) voltage readings at input pins 1 and 5.

The output voltage from the current sensor passes through another unity-gain buffer amplifier, IC3b.

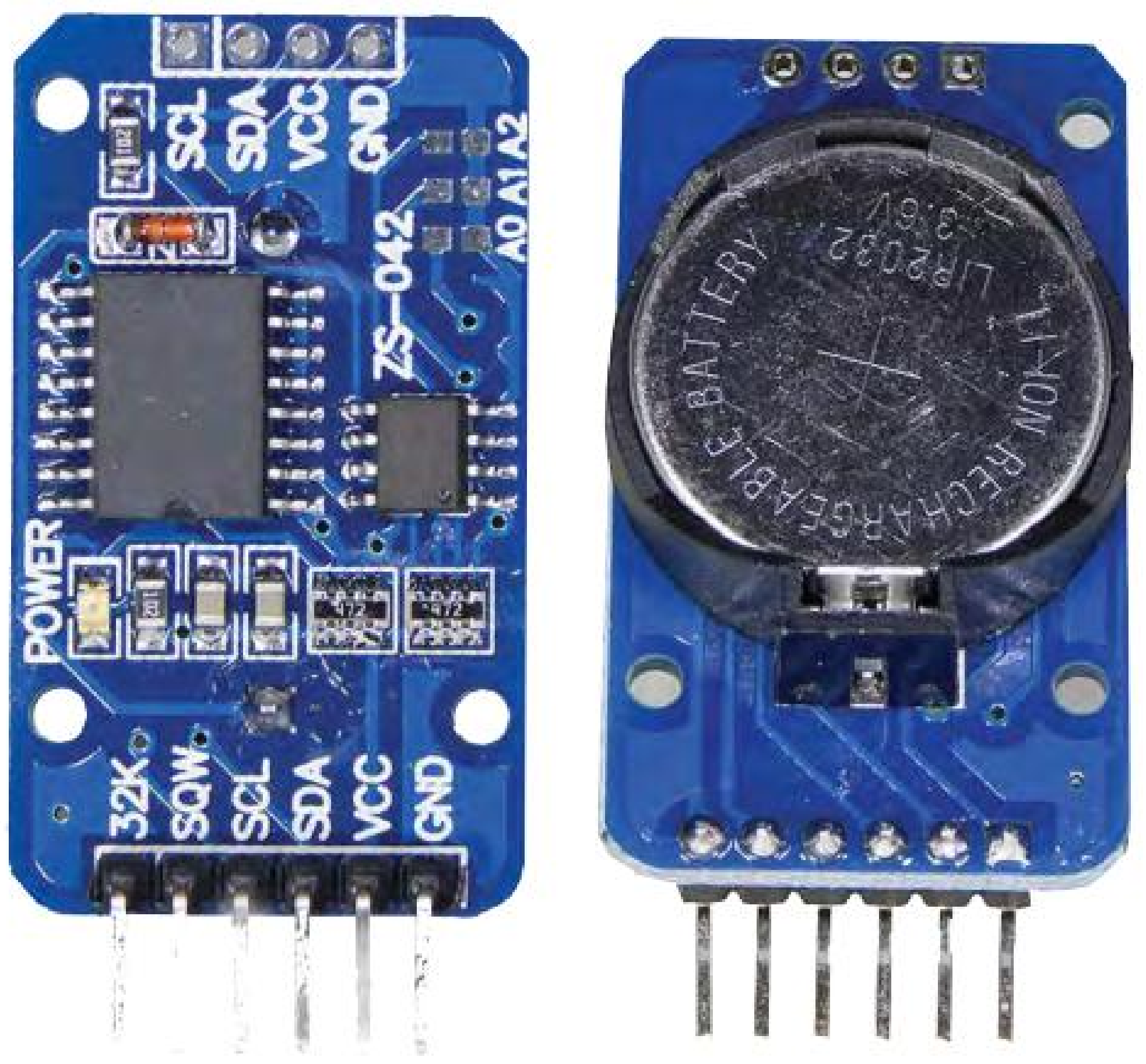
The outputs of the two buffer amplifiers are connected to two inputs of the input multiplexer (selector) inside a Linear Technology LTC1863 12-bit analogue-to-digital converter, IC2. The ADC then takes samples of the voltage and current signals, under the control of the Micromite processor, which communicates with the ADC via an SPI (serial peripheral interface) bus.

So that describes the main measurement part of the new *Appliance Energy Meter*. There is also the real-time clock module (just above the ADC), which connects to the Micromite via an I^{2}C interface and is used to provide the meter's accurate timing (important for time-of-day metering). A USB-to-UART serial module (just above the RTC module), which is connected to the Micromite via a serial interface, is used for downloading the meter's firmware program from your PC and off-loading logged data for analysis.

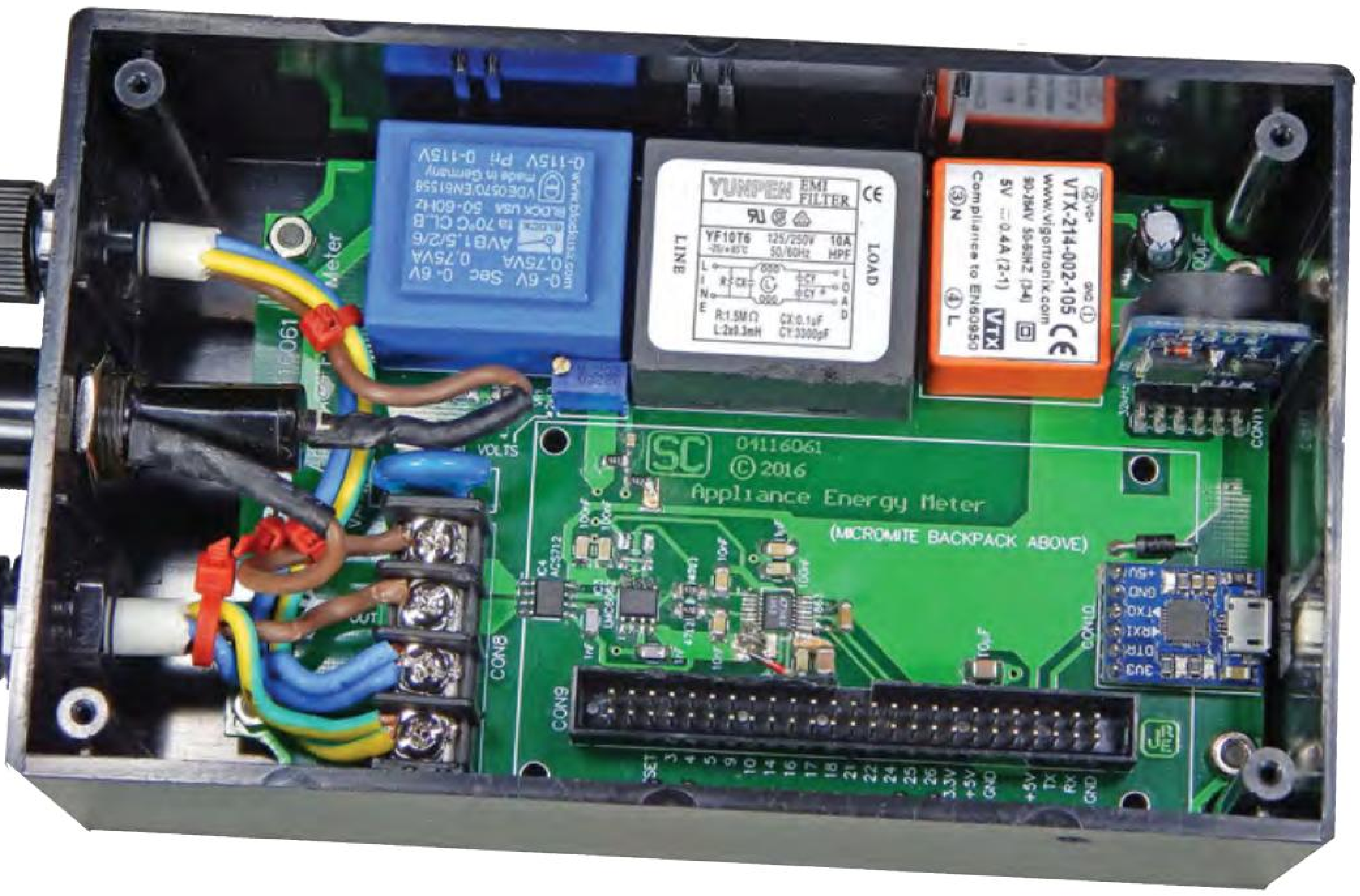
The 230VAC-to-5V DC Power Converter at the upper left corner of Fig.1 provides +5V DC power for all of the meter's circuitry, including the Micromite and its touchscreen display. Note that we did not want to use a conventional transformer, bridge rectifier and regulator circuitry to provide the 5V rail, as it would have been more expensive and would have needed more space on the PCB.

Circuit description

Now have a look at the full circuit diagram of Fig.2. Although it is two pages wide, it is laid out in a very similar way to the block diagram of Fig.1. The internals of the Micromite and its LCD touchscreen are shown on the right-hand page, while the rest of the *Appliance Energy Meter's* circuitry is shown on the left-hand page.


SCL
SDA
VCC
GND
A0
A1
A2
ZS-042
POWER
32K
SQW
SCL
SDA
VCC
GND
RECHARGEABLE BATTERY
LIR2032

The real-time-clock module is soldered onto the PCB once the pins are bent down 90°. It is fitted with a button cell to maintain power and time in the event of disconnection.



Here's the completed *Energy Meter* prototype (without *BackPack*) – it connects to the long IDC socket (CON9) at the bottom of the picture.

There are a few items in the pink shaded 'live' area of the circuit at far left which were not shown in Fig.1 – namely fuse F1, an MOV (metal-oxide varistor) and the EMI filter module connected ahead of the 230VAC input to the VTX-214-002-105 power converter. There's also a four-way screw terminal strip (CON8) used to make the mains input and output connections, at left centre.

Fuse F1 is there to prevent damage to the meter circuitry (and components, especially current sensor IC4) in the event of a serious overload. The MOV prevents damage to the *Appliance Energy Meter* circuitry in the event of a damaging over-voltage spike on the incoming mains lines.

The EMI filter suppresses any switching noise from the Vigortronix 230VAC/5V DC converter which would potentially create problems for the voltage and current measurement circuitry (and possibly affect radio or TV reception).

Transformer T1 has its secondary voltage (nominally 12V) divided down to a measurable level by the voltage divider formed by the 22kΩ and 2.2kΩ resistors. Then the divider's AC output voltage (around 3.25V peak-to-peak) is coupled to the input of buffer IC3a via a 1µF capacitor, while pin 3 of IC3a is DC biased at +2.5V so the signal fed to the ADC (IC2) swings around this voltage (which suits the ADC).

The 1nF capacitor from pin 3 of IC3a to ground and the 100nF capacitor from pin 1 of IC2 to ground provide filtering of any HF noise which may be present on the signal from T1, so that it does not affect the voltage reading accuracy.

Hall Effect current sensor IC4 has an output signal centred at +2.5V (half its supply voltage) which varies either above or below this level, by 100mV/A, depending on the direction of current flow through the sensor.

The circuitry around the LTC1863 ADC (IC2) is also straightforward. It contains its own high-precision voltage reference, with its output available at pin 10. This reference goes to pin 8 of the device, which is being used as the common input for the other inputs to the device, so that the conversion result is close to zero for voltages around 2.5V. The 2.2µF and 100nF capacitors from pin 8 to ground ensure that this reference voltage is noise free.

The current sensor signal is buffered by rail-to-rail CMOS op amp IC3b and passes through a 47Ω/100nF low-pass filter to remove any RF signals that may have been picked up.

IC4 also has a 100nF capacitor from its FILTER pin (pin 6) to ground, which works with an internal 1.7kΩ resistance to reduce the output noise from the Hall effect sensor and also reduce its bandwidth to around 3kHz, to suit the sampling rate (about 5kHz) that we are using to measure the mains current.

Note that a 16-bit version of the ADC, part code LTC1867, is also available. In theory, this might provide slightly improved current resolution if substituted for the LTC1863. The software is designed to work with either part, although we haven't tested the LTC1867. We expect the difference in performance to be small in this application.

As noted above, ADC IC2 is controlled by the Micromite via its SPI interface, with the lines connected to pin 14 (SDI), pin 13 ($\overline{\text{SDO}}$), pin 12 (SCK) and pin 11 (CONV/$\overline{\text{CS}}$).

Basically, the Micromite sends sampling command words to IC2 via the SDI line, and receives the sampled data back via the SDO line. The SCK line provides the serial clock pulses for all transactions, while the CONV/$\overline{\text{CS}}$ line is used to select the ADC and direct it to take each sample.

Note that we haven't used the Micromite's hardware SPI pins for communications (pins 3, 14 and 25) but rather general purpose I/O pins 9, 10 and 24. The reason for this is that the hardware SPI pins are used to drive the TFT display and touch sensor and we need to have a dedicated SPI bus to allow continuous sampling, even while the display is in use.

The two remaining circuit sections to discuss are the RTC (real-time clock) module and the USB-serial converter module (both on the left-hand page).

The RTC module is based on a Maxim DS3231 'extremely accurate' RTC chip, which includes its own 32kHz crystal and a built-in I^{2}C interface. The module we've used (shown in the photos) has provision for a 3V button cell to keep time when power is removed from the meter. It also includes pull-up resistors on the I^{2}C SDA and SCL lines, so these are not needed on our main PCB. The RTC module also hosts an AT24C32 4KB EEPROM (the smaller IC next to the DS3231 chip, visible in the photo at lower-left). This shares the same I^{2}C bus as the real-time clock.

We use this chip to store logging duration, accumulated power usage and cost information, so that if there's a blackout or brownout and the unit resets, you don't lose all the data. However, note that logged data is stored in RAM as the EEPROM is too small.

The USB-serial converter module is based on a Silicon Labs CP2102, which is a complete USB-to-serial interface. The module is about the size of a postage stamp and has a micro-USB socket on one end and a set of connections for its TTL serial port on the other.

In our *Appliance Energy Meter*, the module connects to the Micromite serial port via the RXI and TXO lines, to allow the Micromite to communicate with your PC to download logged data. The same interface is used initially to program the meter's firmware, via your PC.

Measuring power

Since the Micromite used here only has support for one hardware SPI bus, we've had to implement the second SPI bus in software, ie, by 'bit banging'. As there are several thousand ADC measurements per second, this is written in 'C' and embedded in the Micromite BASIC code using the 'CFUNCTION' statement.

2812C-SZ
J1
J2

The energy meter uses the *Micromite BackPack* with a 2.8-inch LCD touchscreen (avaiable from micromite.org).

This is also necessary to allow the sampling to occur even while the BASIC interpreter is busy updating the display or performing other tasks. We'll have more details on how the software works in *Part 2*, next month.

But let's now go over how the unit measures RMS voltage, current and power. First, the CFUNCTION sets up the PIC32's internal TIMER1 at boot to call an interrupt routine (also written in C) at approximately 10kHz. This alternately samples inputs 1 and 5 of IC2, resulting in a pair of instantaneous (and more-or-less simultaneous) voltage/current readings at 5kHz.

Each time a pair of readings is completed, they are squared and accumulated into two separate 64-bit memory locations. They are also multiplied together and accumulated into a third location (for VA) and finally, if they are of the same polarity, also accumulated into a fourth location (for true power).

The software detects voltage zero-crossing events and when this occurs, the accumulated registers are divided by the number of readings made since the last zero crossing and the square root taken.

This yields RMS voltage, current, VA and power for the half-cycle. Multiple half-cycle readings are averaged for display and the power factor computed by dividing the real power by the apparent power.

The average power reading is multiplied by the number of mains cycles it occurs over, and then divided by the detected mains frequency to compute an energy figure, which is accumulated to give total energy consumption.

Cost is computed similarly, after applying the current tariff, with the real-time clock used to determine the one to use.

The hardware: a quick preview

The *Touchscreen Appliance Energy Meter* is built into a UB1 jiffy box measuring 158 × 95 × 53mm. Apart from the mains fuseholder and the two cable glands used for entry of the mains input and output cables, everything else is mounted on three small PCBs – the two used by the *Micromite BackPack* and its LCD touchscreen, and the main PCB we have designed for the rest of the *Appliance Energy Meter's* circuitry. (The real-time clock and USB/serial converter modules are pre-assembled).

The main board is available from the *EPE PCB Service*, coded 04116061, and measures 132 × 85mm. All components except for those used in the *Micromite LCD BackPack* are mounted on its top-side.

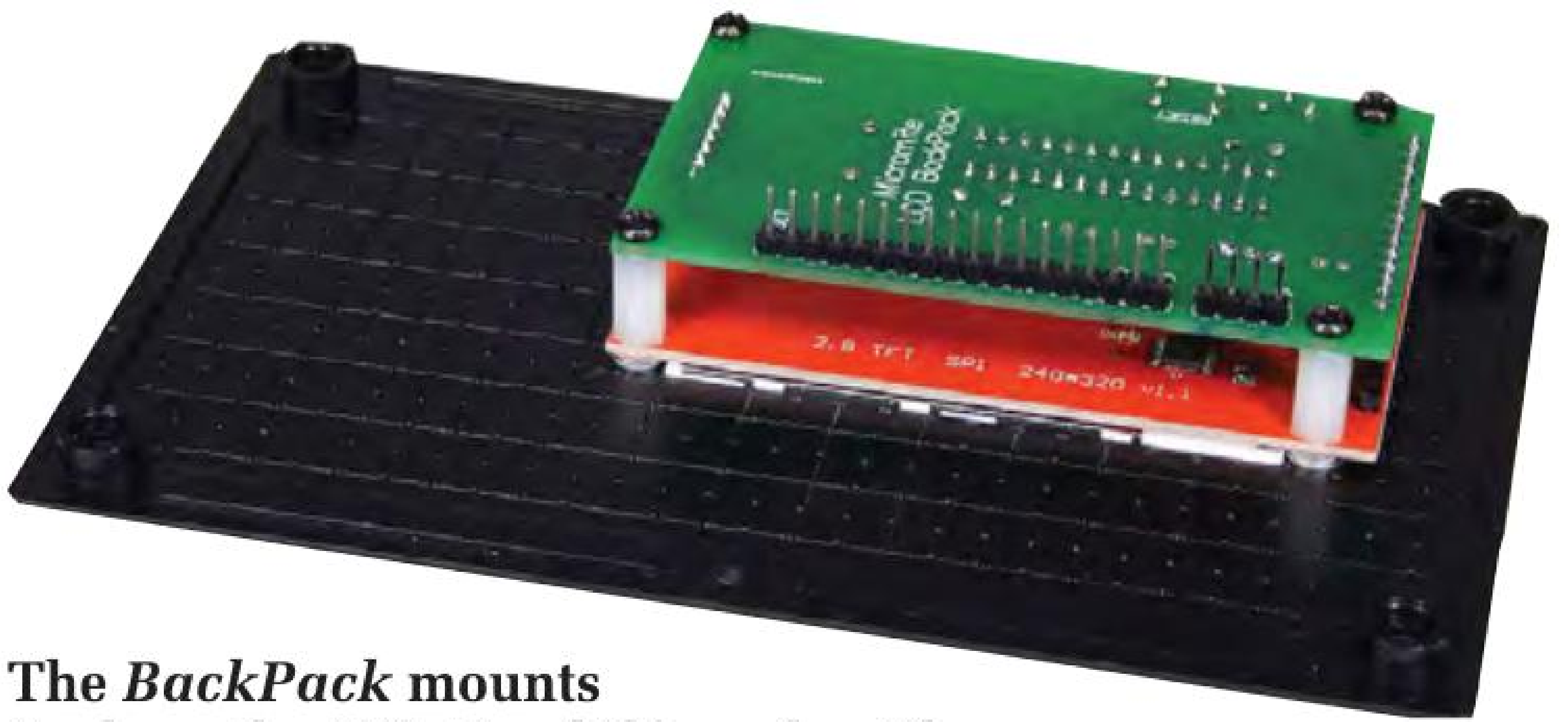
Parts List – Appliance Energy Meter

1 double-sided PCB, available from the *EPE PCB Service*, coded 04116061, 132 × 85mm
1 UB1 jiffy box, 158 × 95 × 53mm
1 Micromite LCD BackPack kit with 2.8-inch TFT colour touchscreen (**available from micromite.org**)
1 real-time clock module, DS3231 based
1 CR2016, CR2025, CR2032 or LIR2032 button cell
1 USB-to-UART serial converter module
1 Block AVB 1,5/2/6 2 × 115V to 2 × 6V 1.5VA transformer
1 Vigortronix VTX-214-002-105 AC-DC switchmode power supply, 5V output at 400mA
1 Yunpen YF10T6 EMI filter, 250VAC/10A
1 metal-oxide varistor (MOV), 275VAC working/115J
1 PCB-mounting 4-way terminal barrier, 300V/15A rating with 8.25mm spacing (CON8)
2 SIL pin headers, 6-pin vertical (CON10, CON11)
1 50-way DIL box header, PCB mounting (CON9)
2 50-way IDC ribbon cable sockets
1 100mm length of 50-way ribbon cable
8 6mm-long M3 nylon or polycarbonate screws
4 M3 tapped 6.3mm nylon spacers
4 10mm-long M3 screws
4 12mm-long M3 tapped spacers
4 6mm-long M3 screws
12 M3 flat washers
1 panel-mounting 3AG fuseholder, 'very safe' type
1 15A slow-blow 3AG fuse cartridge
1 230V/10A extension cord, 3m long
2 cable glands to suit 4-8mm diameter cable

Semiconductors
1 LTC1863CGN#PBF 8-channel 12-bit ADC (IC2; 16-pin SSOP SMD) **or**
1 LTC1867CGN#PBF 8-channel 16-bit ADC (IC2; 16-pin SSOP SMD)
1 LMC6482AIM dual op amp (IC3; 8-pin SOIC)
1 ACS718 Hall effect isolating current sensor (IC4: further details next month)
1 1N5819 40V 1A Schottky diode (D1)

Capacitors
1 1000µF 10V low-ESR electrolytic
2 10µF 16V X5R SMD 3226/3216 (1210/1206 imperial)
1 2.2µF 16V X7R SMD 3216/2012 (1206/0805 imperial)
2 1µF 16V X7R SMD 3216/2012 (1206/0805 imperial)
8 100nF 16V X7R SMD 3216/2012 (1206/0805 imperial)
1 1nF 50V COG SMD 3216/2012 (1206/0805 imperial)

Resistors (All 3216/2012 [imperial 1206/0805] SMD 1%)
2 56kΩ 1 22kΩ 1 2.2kΩ 2 47Ω



The *BackPack* mounts flush on the Jiffy Box lid/panel, with a suitable cutout so you can read/touch it. Accurately machined acrylic panels are available from the SILICON CHIP Online Shop to save you the trouble of cutting the hole.

The user interface

Because the *Energy Meter* has a colour LCD touchscreen, we have put significant effort into the user interface, to maximise the unit's utility. Samples of most (but not all) available screens are shown at right. Note that these are from the prototype and some improvements and additions have been made since they were taken.

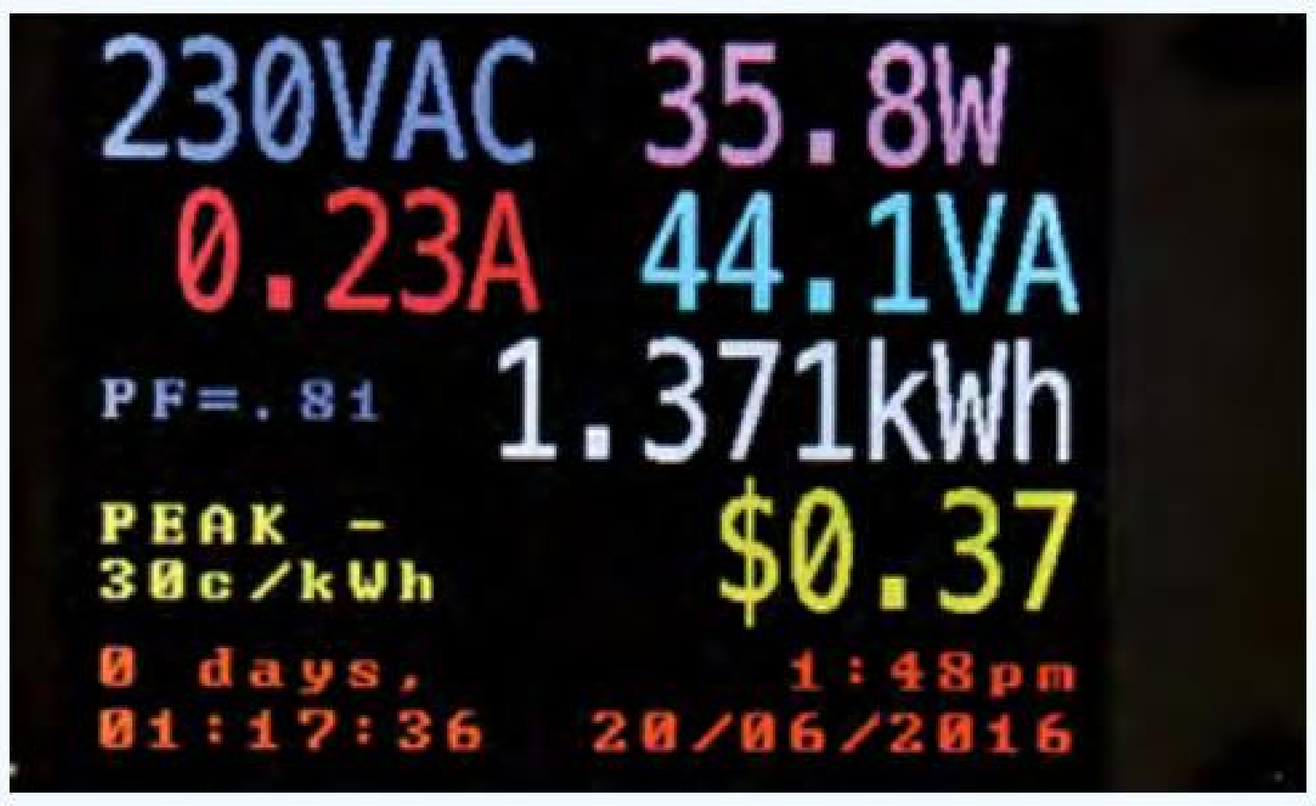
On the main screen, shown at upper-left, pressing on any element in the display takes you to a screen with more information relevant to that particular area. So for example, if you touch on the power figure, you will see a graph of power vs time and pressing on this again takes you to a power histogram.

Similarly, if you touch the time or date, you are taken to a screen where you can set the current time or date and if you touch the logging duration, you can access the logging screen which provides more information and allows you to start, stop or pause logging (and other functions, too).

In fact, the *Appliance Energy Meter* is so feature-packed that we have exhausted both the RAM and Flash memory available in the Micromite Mk2! We had to spend significant amounts of time optimising both types of memory usage before we could fit in all the features that we felt were necessary to make the *Appliance Energy Meter* as useful as possible.

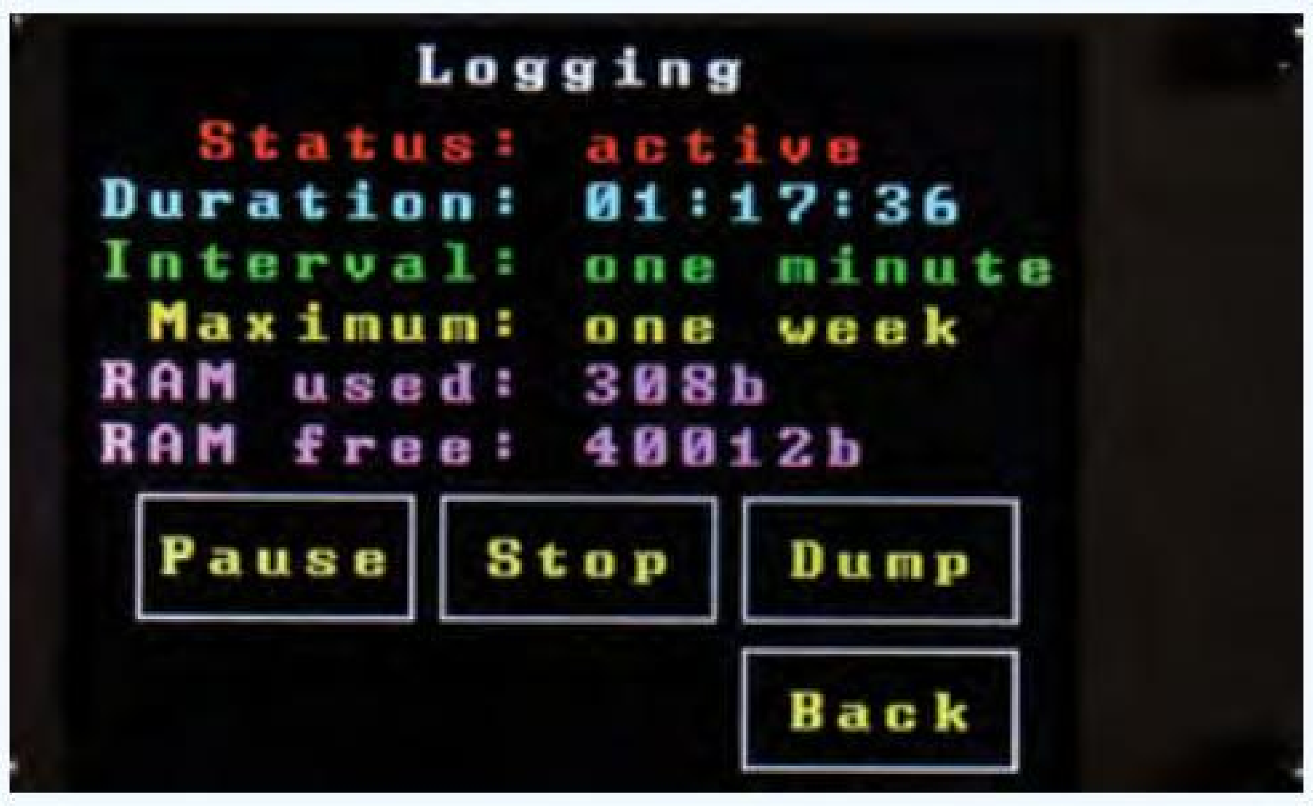
You may notice a trimpot in one of the photos of the assembled prototype PCB. This has been removed from the final design in favour of software calibration, which can be done via the touchscreen, with the unit completely sealed. This is much safer as it doesn't require you to insert a screwdriver into the case while mains power is applied.

In fact, part of the calibration (to account for DC offset in both voltage and current, and noise from the current sensor) is totally automatic. The only manual calibration required is to set the voltage reading so that it matches the actual mains voltage, as determined using a multimeter (more on that next month). You can also calibrate the current readings; however, this is optional and can be done using a DC supply and a DMM.



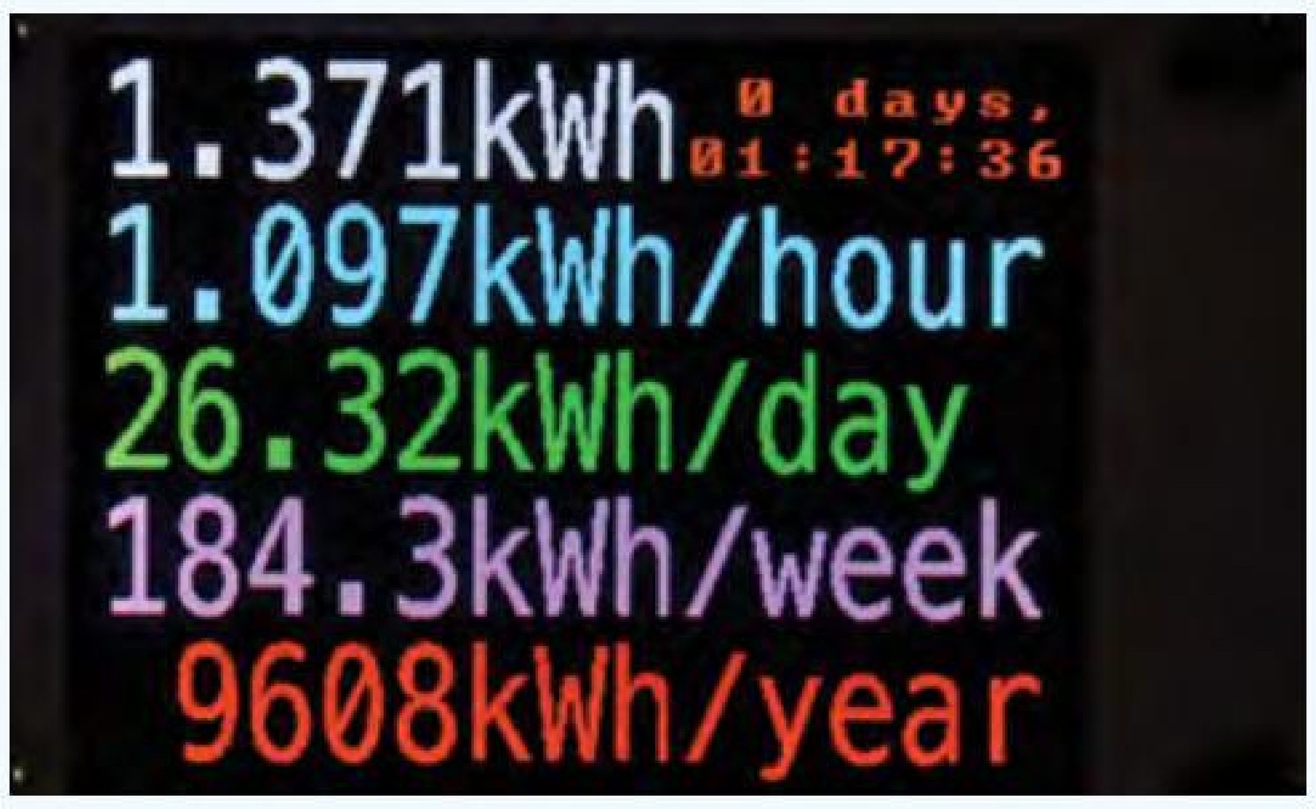
230VAC 35.8W
0.23A 44.1VA
PF=.81 1.371kWh
PEAK - 30c/kWh $0.37
0 days, 01:17:36
1:48pm 20/06/2016

The main screen, displayed at power-up, shows all the most important information at a glance: mains voltage current, real power, VA, frequency, power factor, tariff, accumulated energy and cost, current time and date and logging duration.



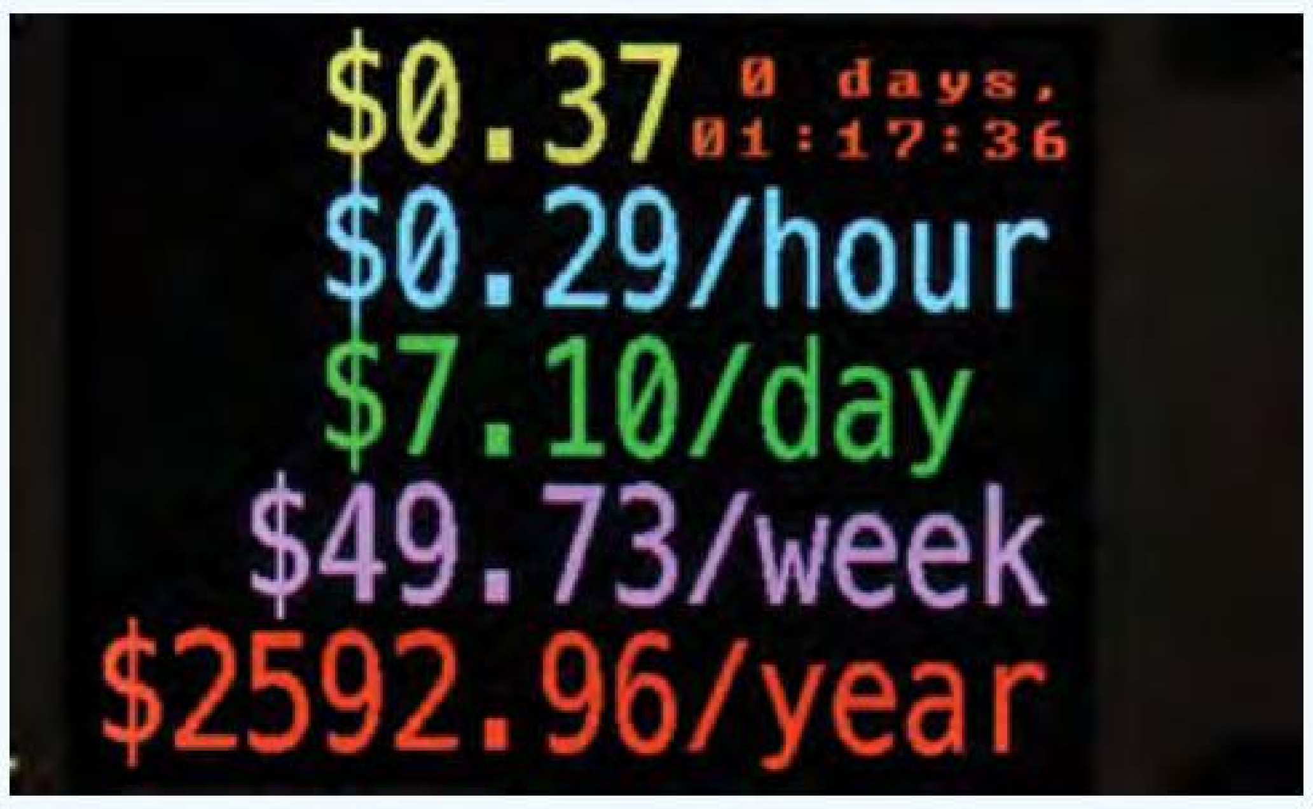
Logging
Status: active
Duration: 01:17:36
Interval: one minute
Maximum: one week
RAM used: 308b
RAM free: 40012b

Touch the logging duration to access this screen with more information, including the logging interval, current and maximum duration and memory usage. It also has buttons to start, stop or pause logging, export the data via USB or access calibration/diagnostics.



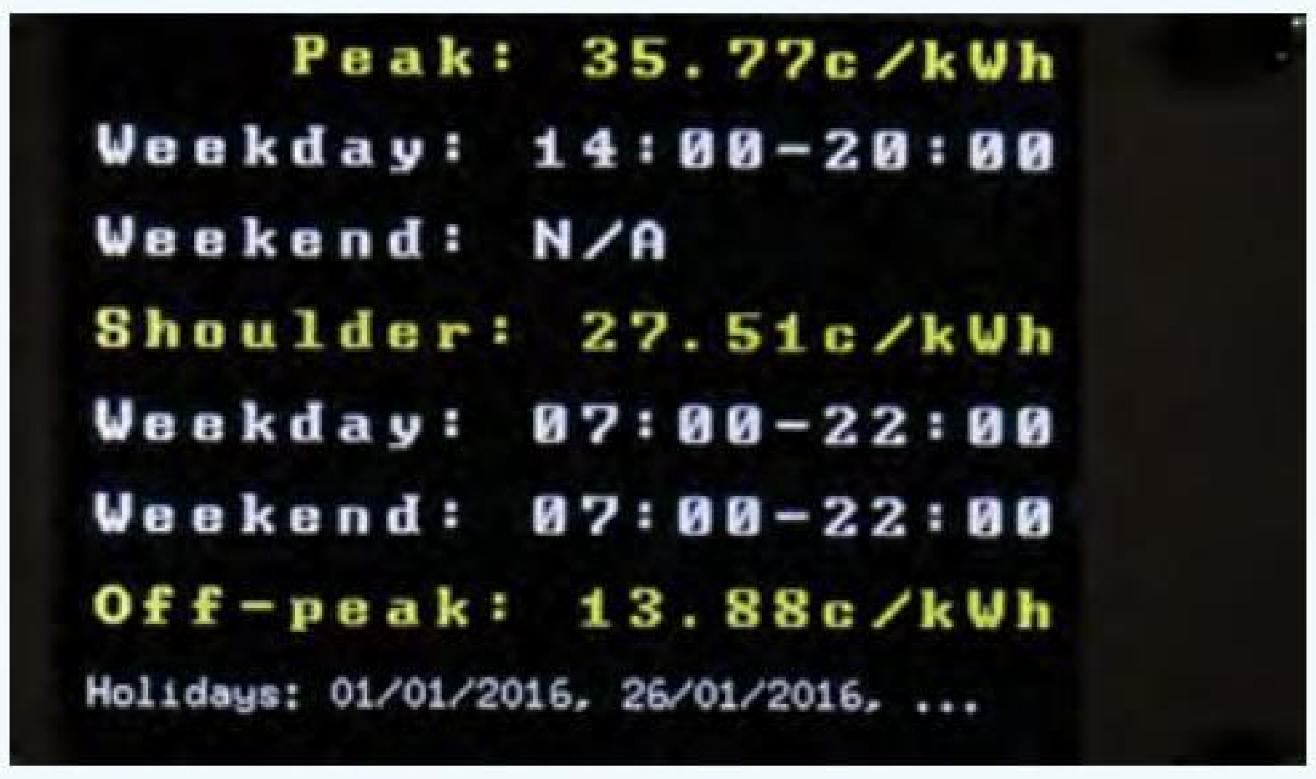
1.371kWh 0 days, 01:17:36
1.097kWh/hour
26.32kWh/day
184.3kWh/week
9608kWh/year

Touch the accumulated energy figure (in kWh) to view estimates of how much energy the load will use in one hour, one day, one week and one year. The longer you leave the unit running, the more accurate these become.



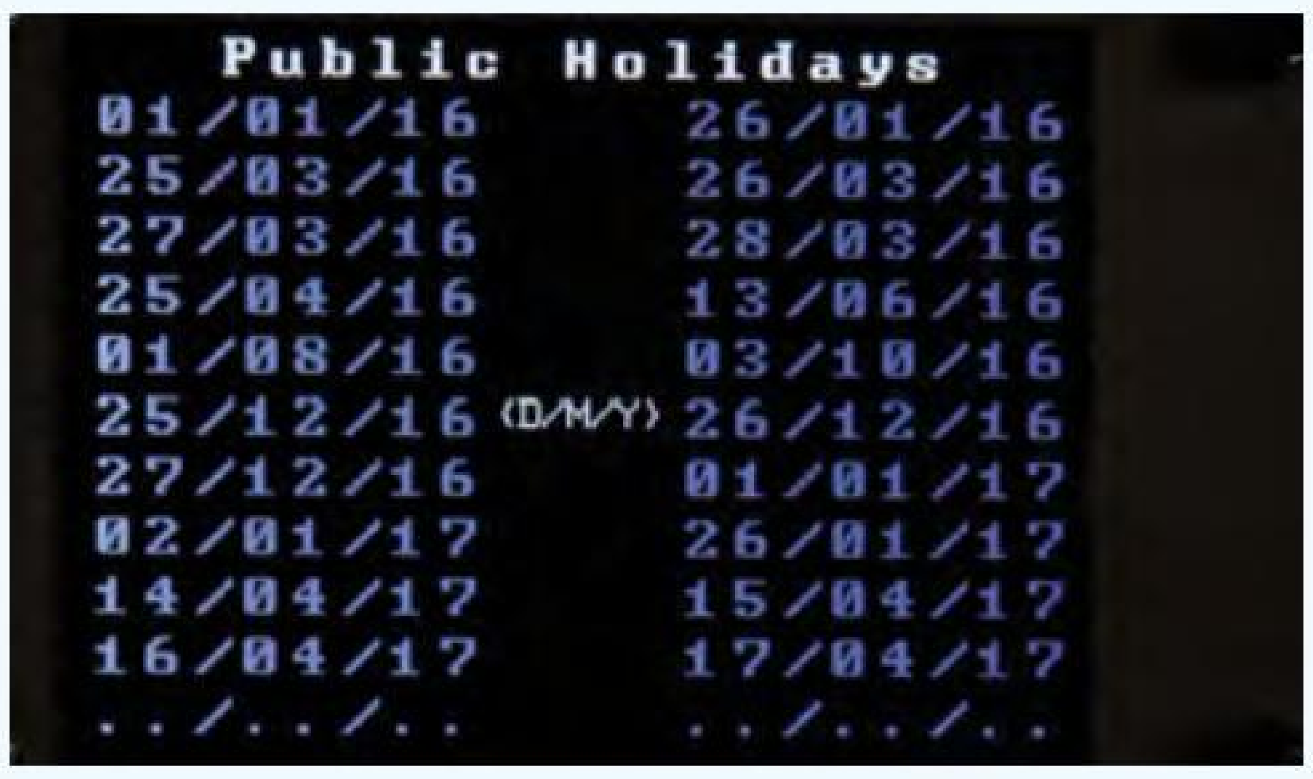
$0.37 0 days, 01:17:36
$0.29/hour
$7.10/day
$49.73/week
$2592.96/year

Touch the accumulated cost figure to view estimates of how much the load will cost to run for one hour, one day, one week and one year. The longer you leave the unit running, the more accurate these become.



Peak: 35.77c/kWh
Weekday: 14:00-20:00
Weekend: N/A
Shoulder: 27.51c/kWh
Weekday: 07:00-22:00
Weekend: 07:00-22:00
Off-peak: 13.88c/kWh
Holidays: 01/01/2016, 26/01/2016, ...

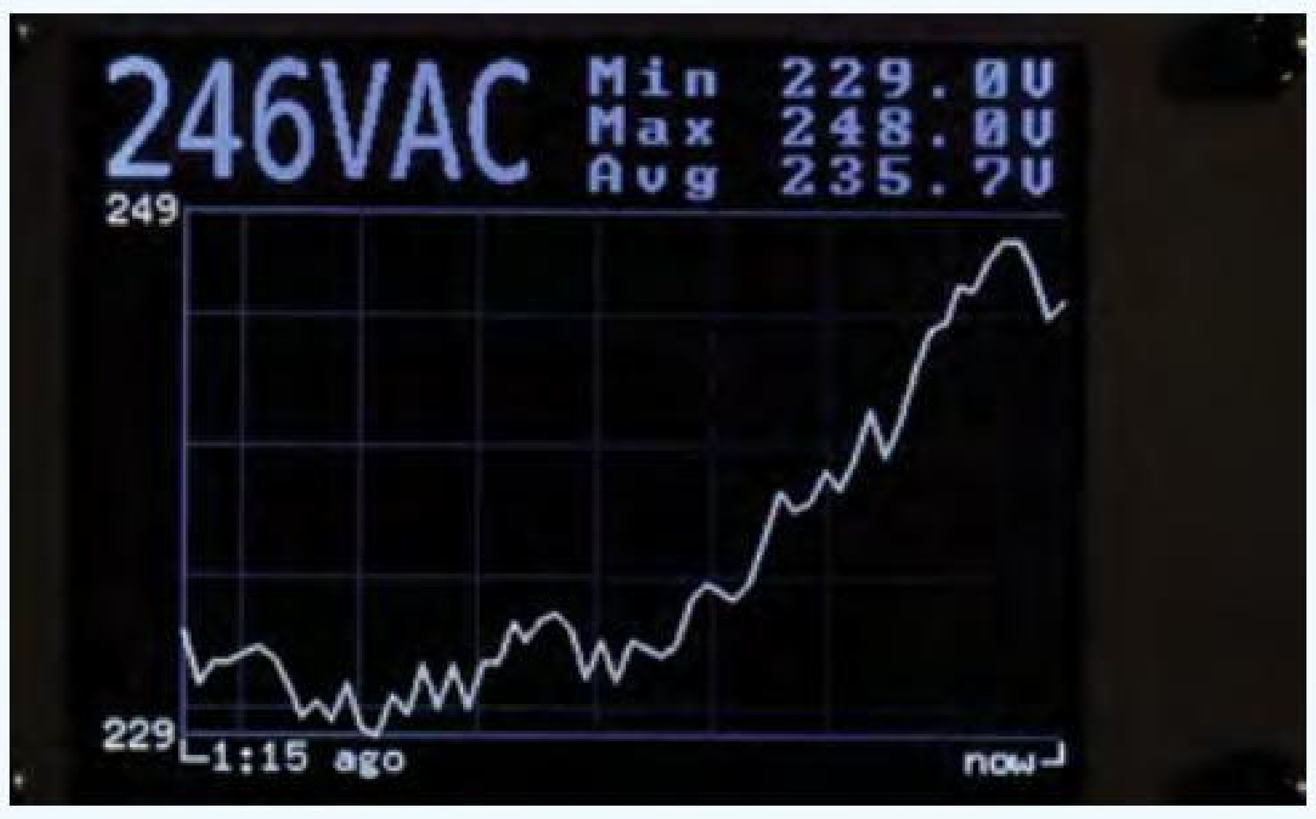
This screen allows you to view and set the three different tariffs and when they apply. Each tariff can have two different start/end times for weekdays or weekends. Public holidays can be programmed in, so that the weekend rate is used on those dates.



Public Holidays

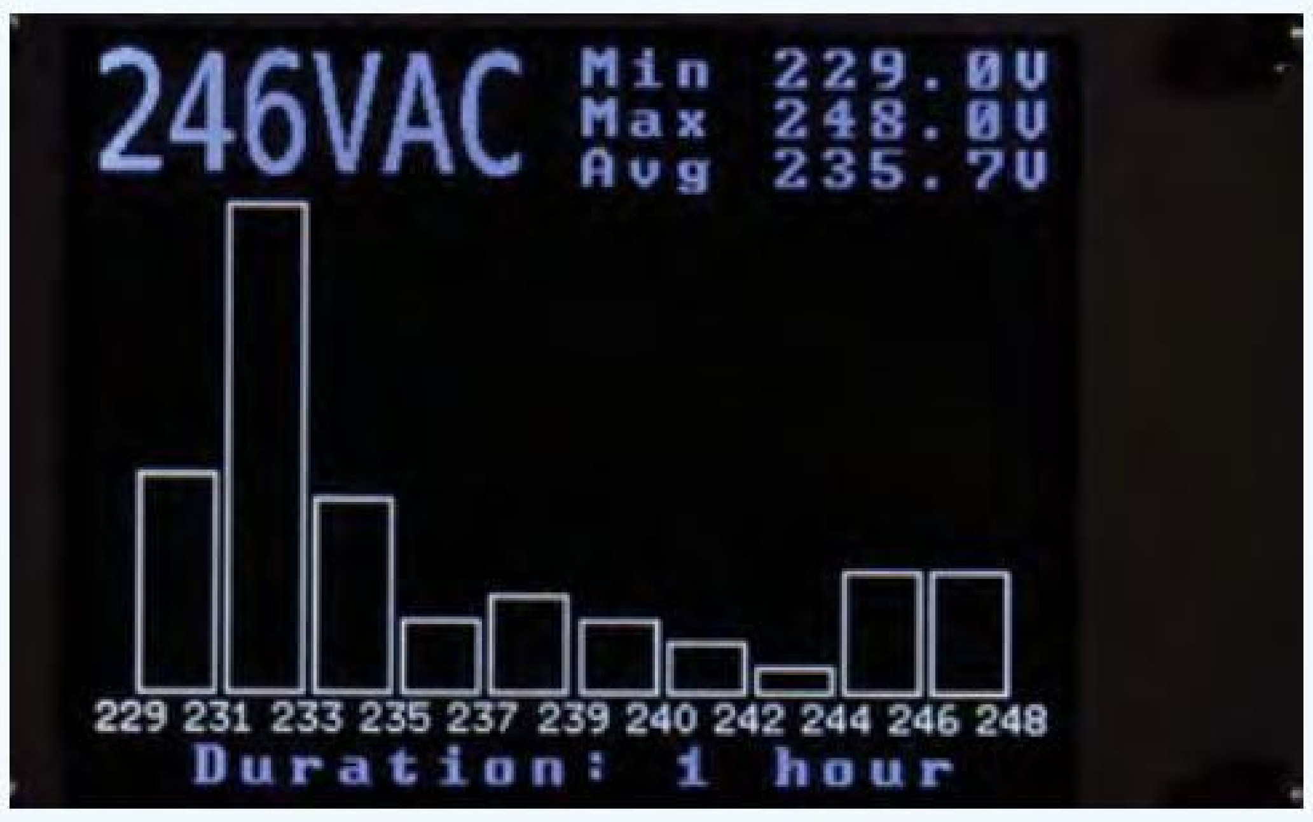
	(D/M/Y)	
01/01/16		26/01/16
25/03/16		26/03/16
27/03/16		28/03/16
25/04/16		13/06/16
01/08/16		03/10/16
25/12/16		26/12/16
27/12/16		01/01/17
02/01/17		26/01/17
14/04/17		15/04/17
16/04/17		17/04/17
../../..		../../..

Touch the public holidays on the screen to the left and you can enter in up to 22 different dates to indicate weekdays that should be treated as weekends for calculating the current tariff. (Check if your energy supplier uses this billing scheme.)



246VAC Min 229.0V Max 248.0V Avg 235.7V

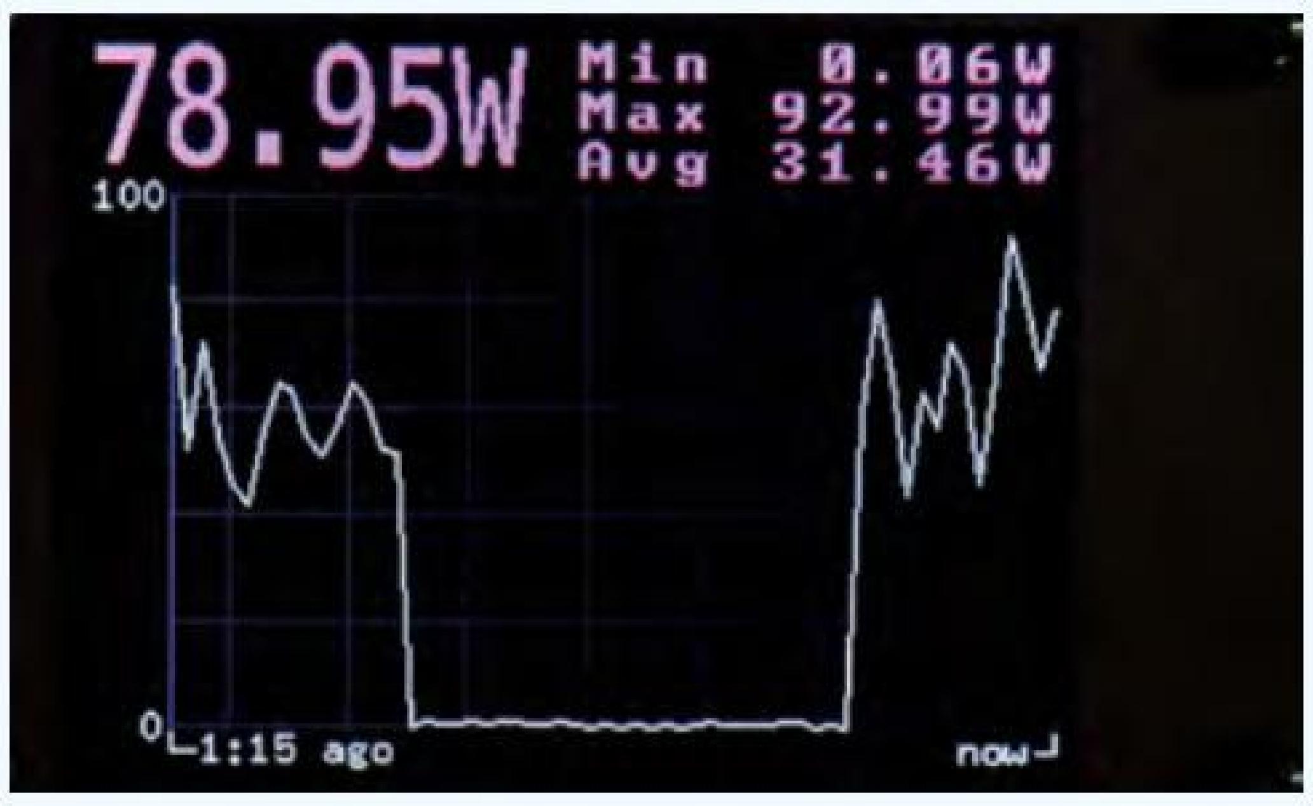
While logging is active, data is stored in memory at one, 10 or 60-second intervals and can be plotted by touching on the parameter. Here's a sample graph of the mains voltage over time.



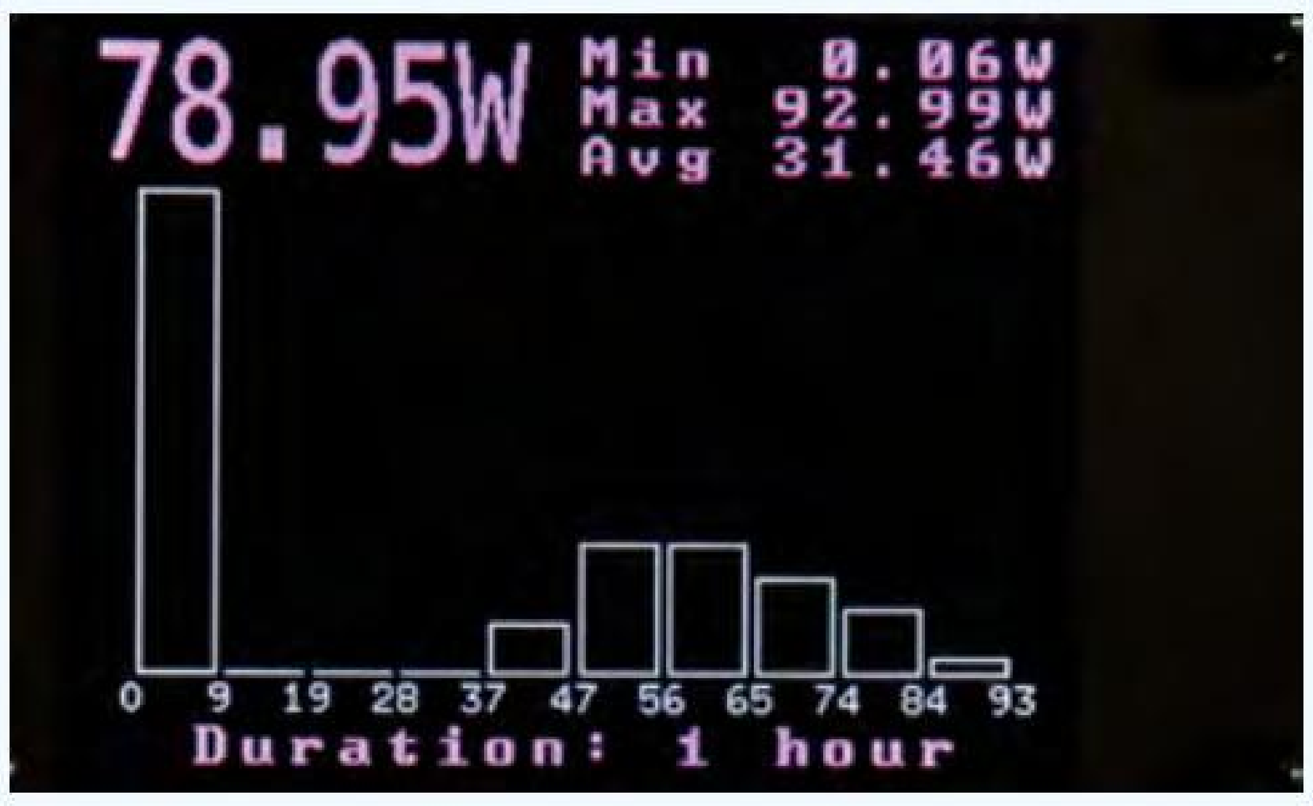
246VAC Min 229.0V Max 248.0V Avg 235.7V

Duration: 1 hour

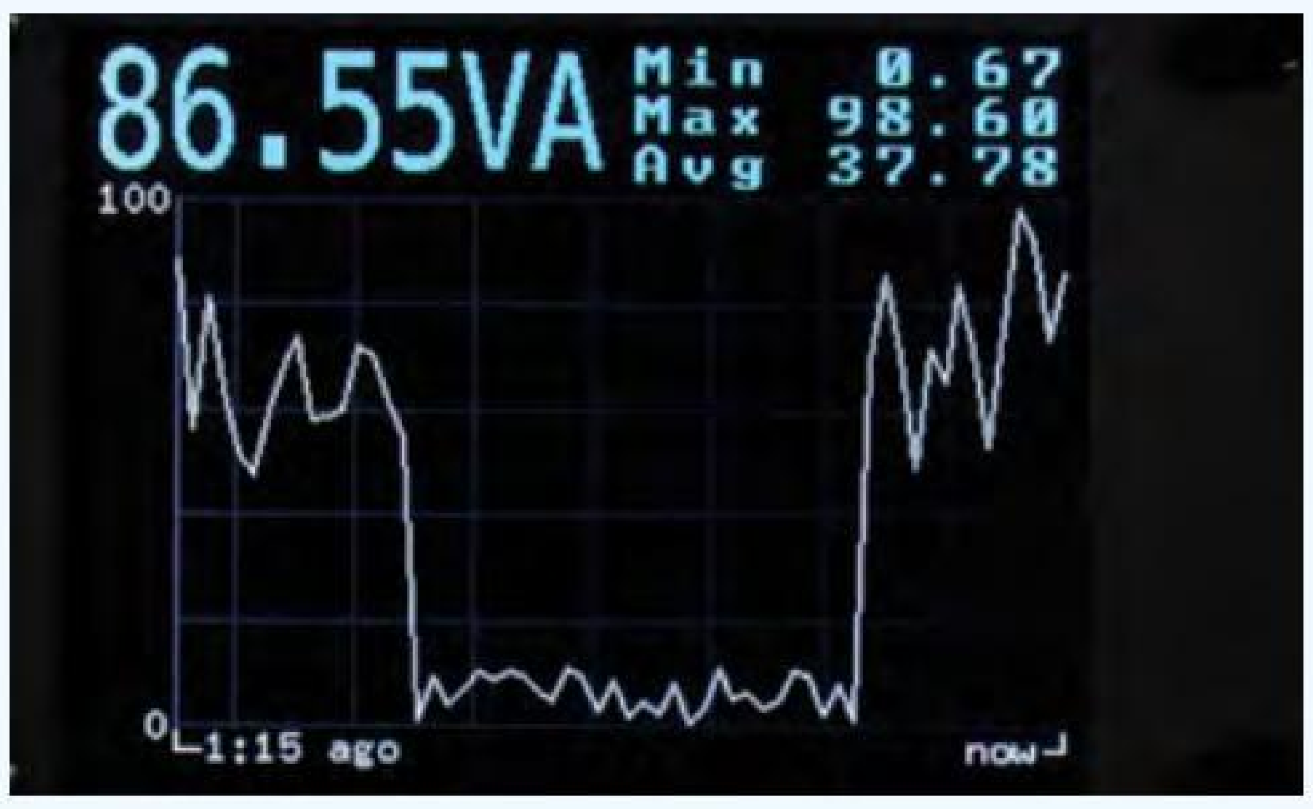
Touching the voltage/time graph takes you to histogram mode. The selectable durations are the same as before, but now you can see what proportion of the time the mains voltage spends at various different voltage levels.


78.95W
Min 0.06W
Max 92.99W
Avg 31.46W
100
0
1:15 ago
now

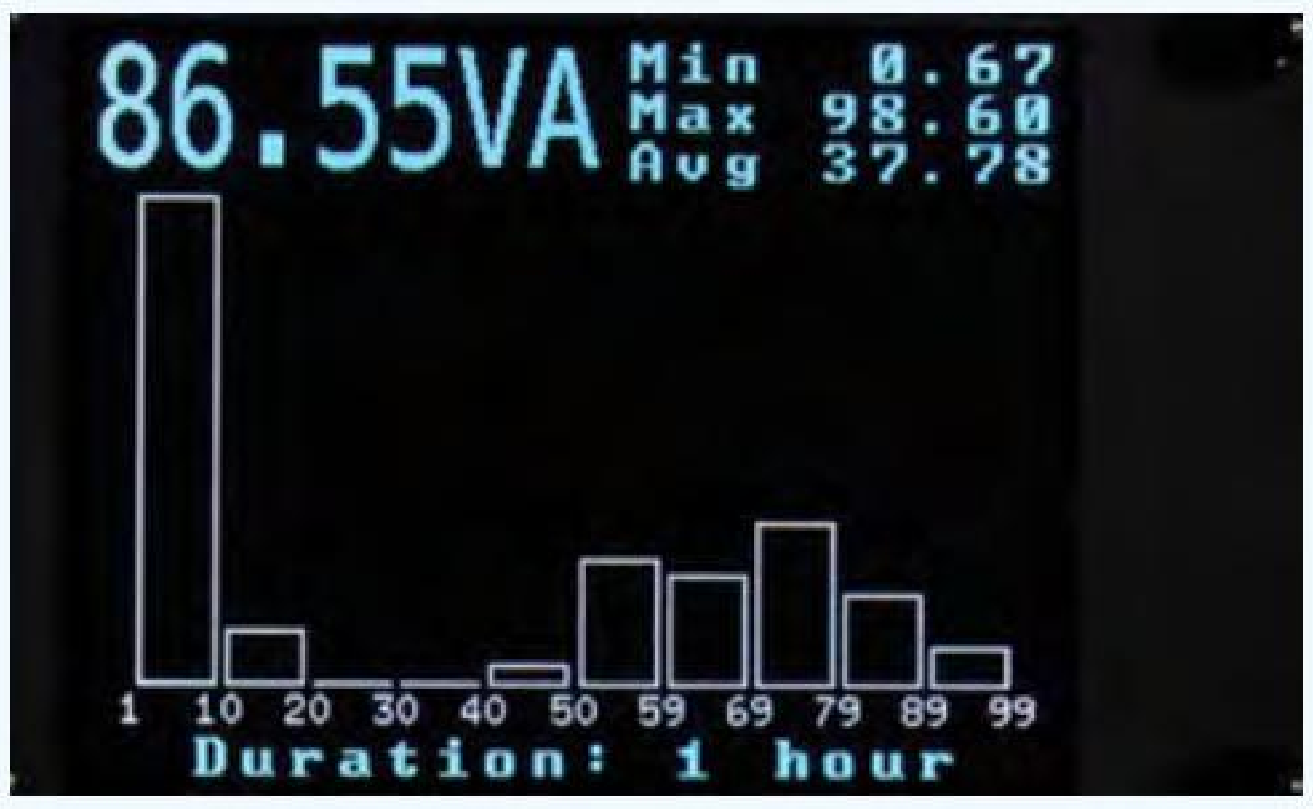
The power vs time graph is accessed by touching the power figure. All time-based graphs can be changed between one-hour, one-day and one-week periods. If insufficient data is available, it shows what has accumulated so far.


78.95W
Min 0.06W
Max 92.99W
Avg 31.46W
0 9 19 28 37 47 56 65 74 84 93
Duration: 1 hour

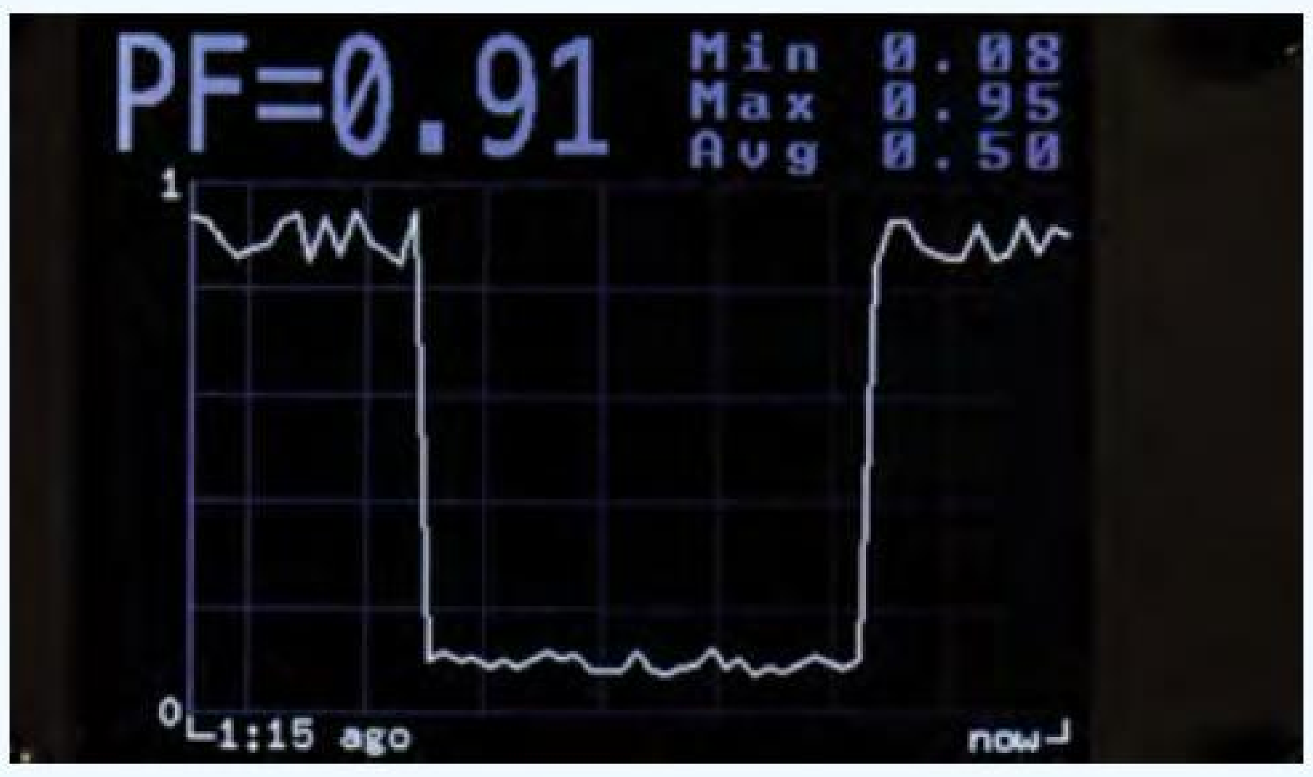
All values that are logged can be displayed as either graphs or histograms. Minimum, maximum and average readings are shown at the top of each graph or histogram and indicate the range of values measured during the displayed period.


86.55VA
Min 0.67
Max 98.60
Avg 37.78
100
0
1:15 ago
now

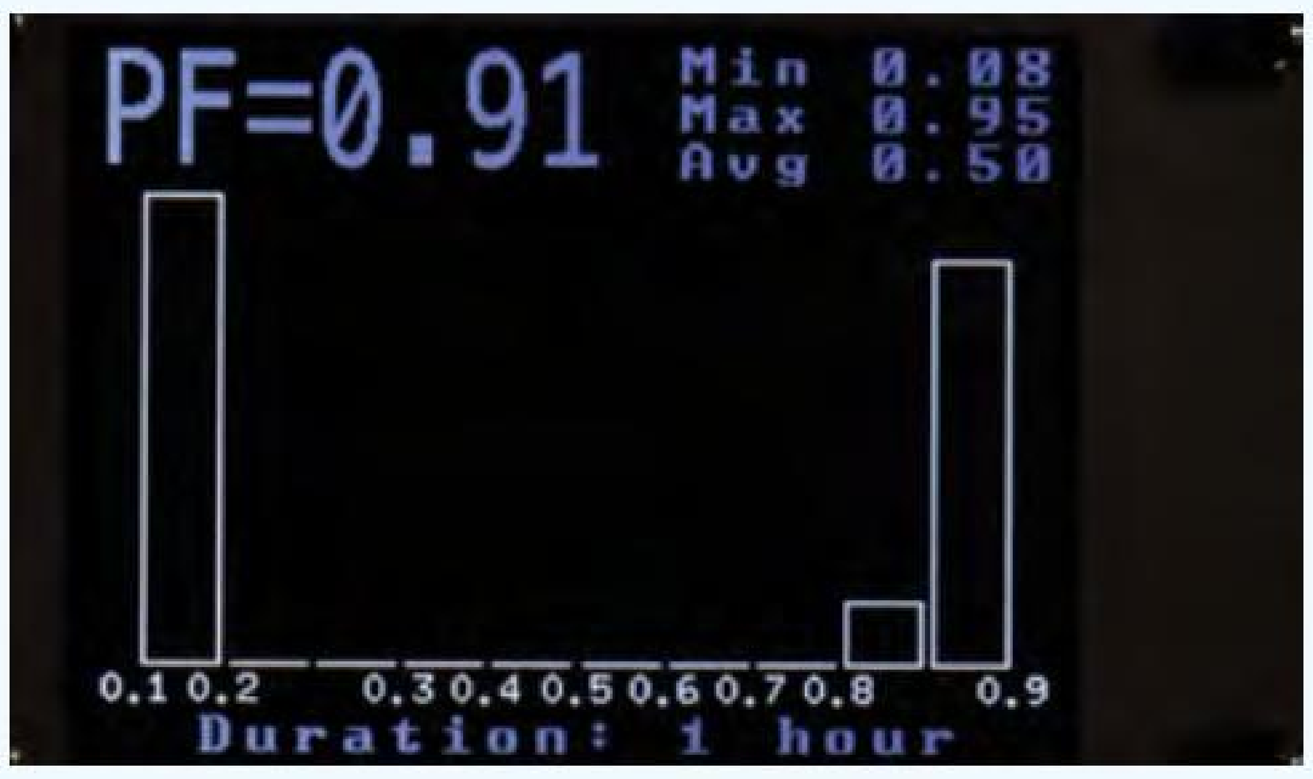
Similarly, VA (apparent power) can be graphed. While the duration can be changed, the right-most point is always the current reading. If you leave a graph on screen, once sufficient data is available, it 'scrolls' right-to-left.


86.55VA
Min 0.67
Max 98.60
Avg 37.78
1 10 20 30 40 50 59 69 79 89 99
Duration: 1 hour

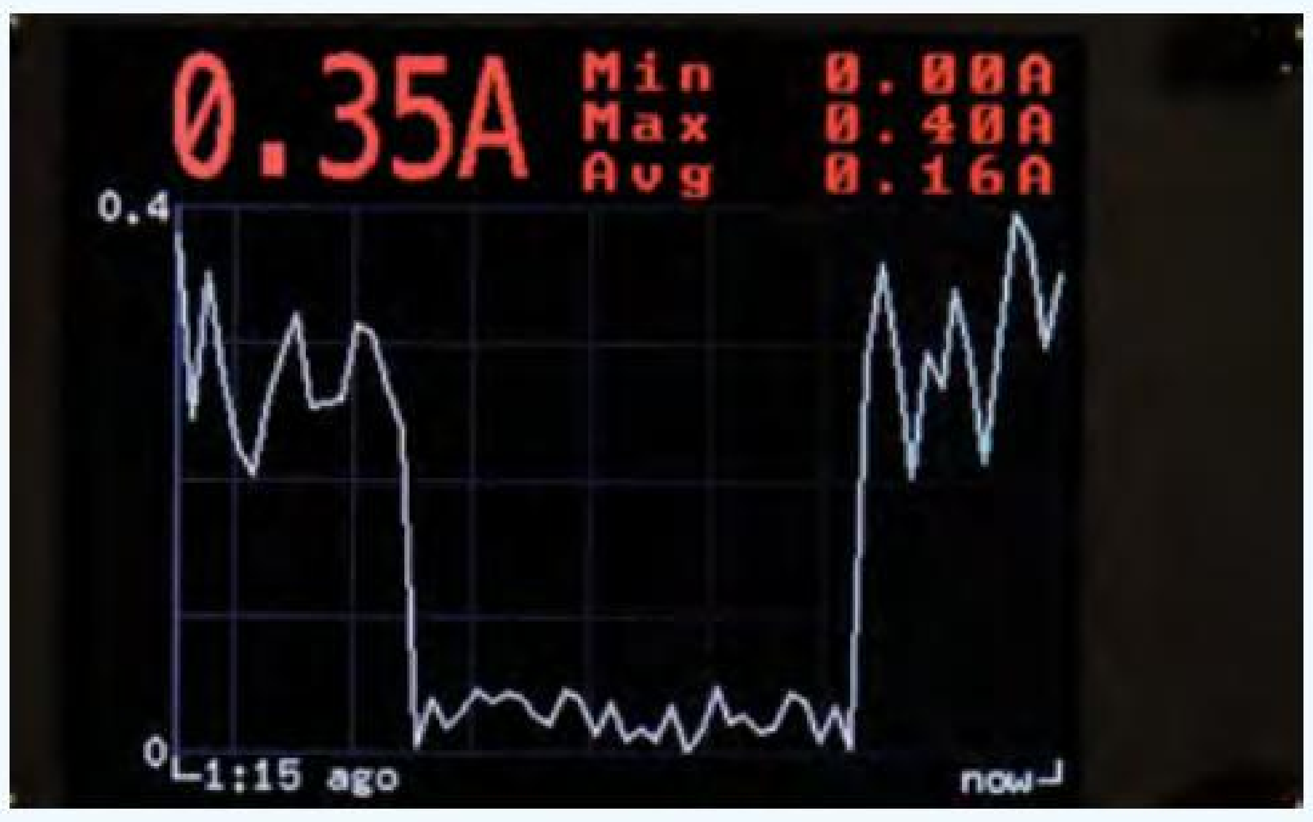
Histograms (such as this one for apparent power) also update automatically when they are left on the display, and like the graphs, represent data for the selected duration to the present.


PF=0.91
Min 0.08
Max 0.95
Avg 0.50
1
0
1:15 ago
now

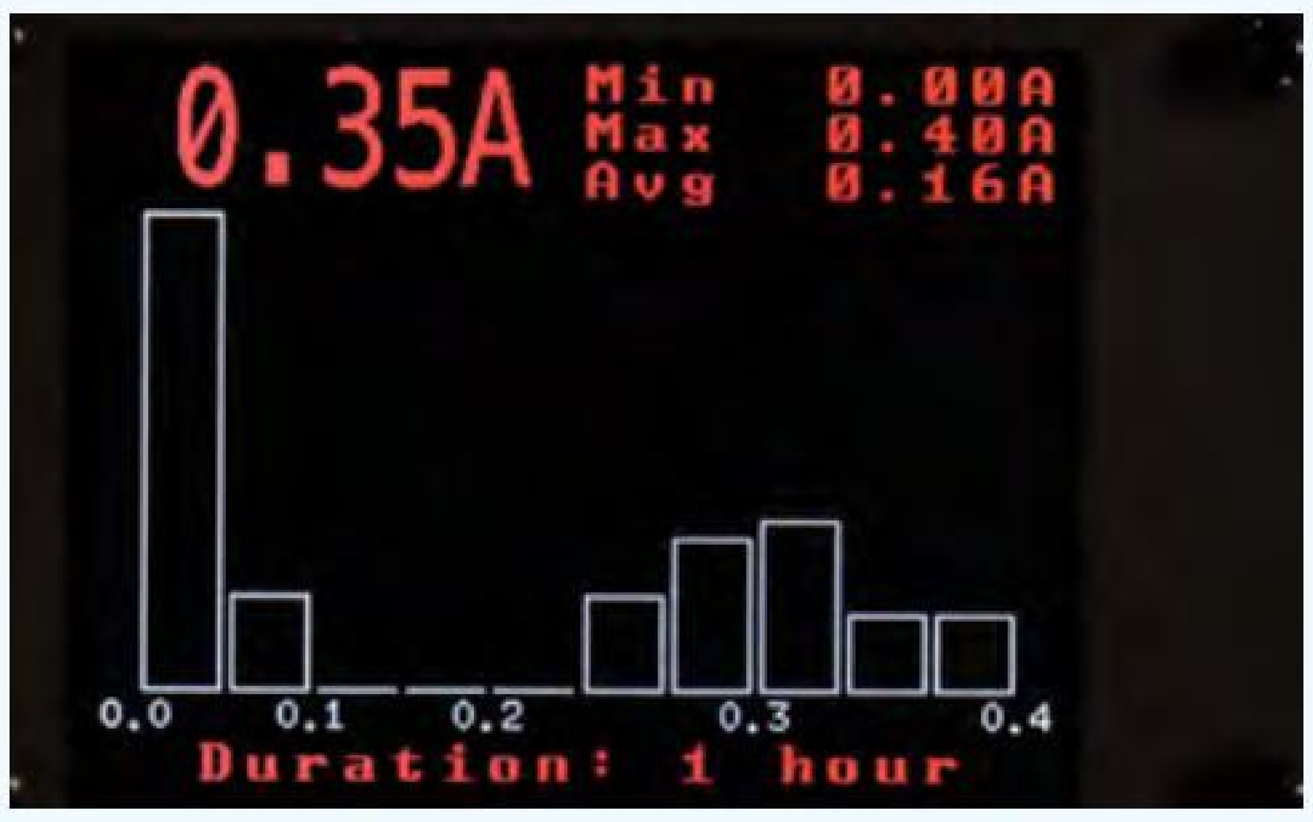
While minimum and maximum values are shown, note that data is averaged over the logging interval (between one second and one minute) so brief excursions to one extreme or the other may not always be reflected in these readings.


PF=0.91
Min 0.08
Max 0.95
Avg 0.50
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
Duration: 1 hour

In histogram mode, 10-12 bars are normally shown and the horizontal scale is automatically determined by the lowest and highest readings over the logging period. In this case, the power factor is always low (with the load off) or high, never in between.


0.35A
Min 0.00A
Max 0.40A
Avg 0.16A
0.4
0
1:15 ago
now

The vertical axis for graphs is also chosen automatically to show the whole range of values logged, hence for loads which draw more current than this, the amps scale will be more compressed.


0.35A
Min 0.00A
Max 0.40A
Avg 0.16A
0.0 0.1 0.2 0.3 0.4
Duration: 1 hour

Finally, a histogram of load current for the last hour, which shows how the current is spread over a range from 250-400mA when the load is on and is close to zero for those times it switches off.

PoLabs

For more information or
software download please visit

www.poscope.com/epe

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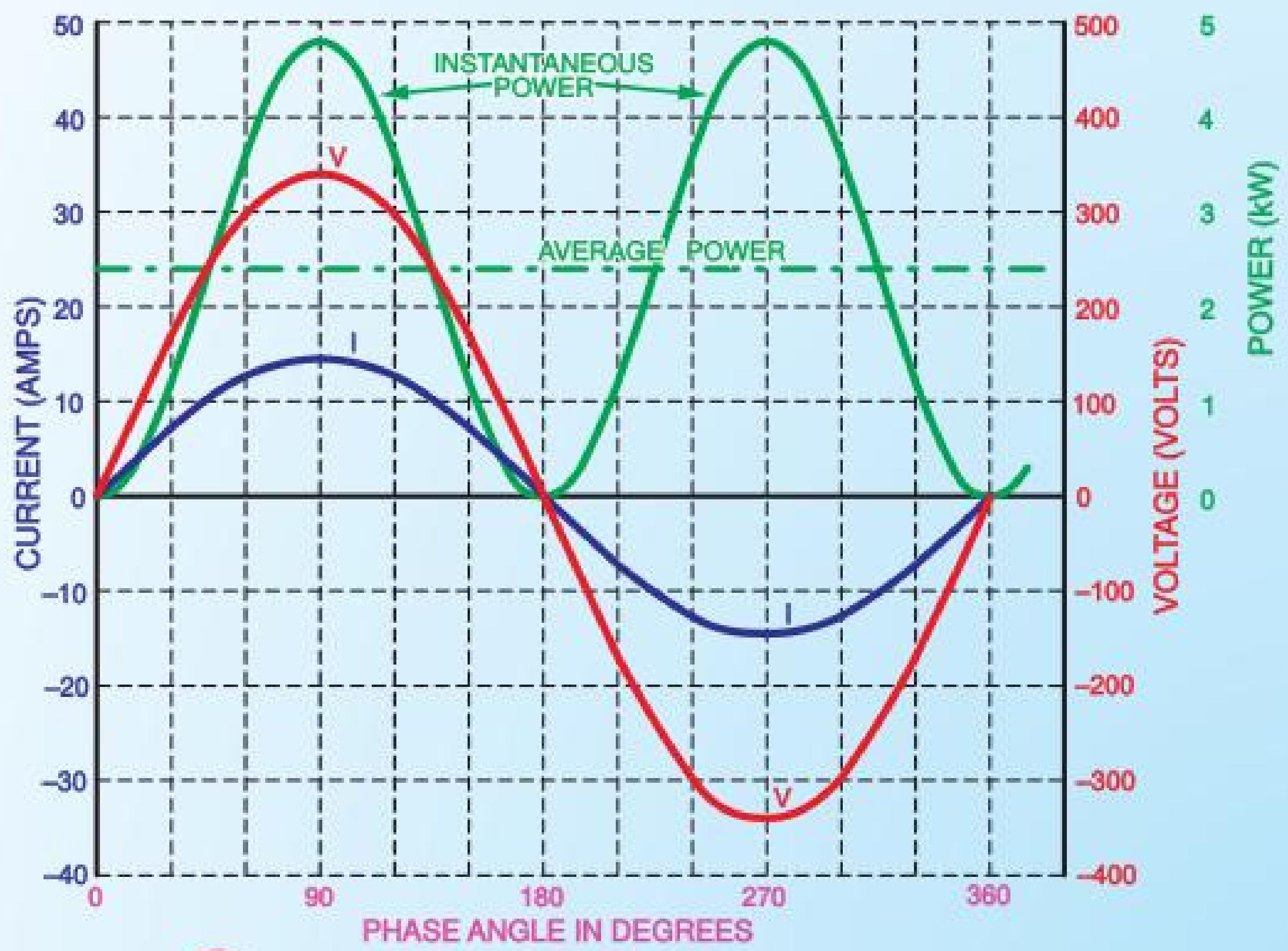
Volts, amps, kilowatts and energy

In a DC (direct current) system, the power being used by a load can be worked out quite easily by measuring the voltage (V) across the load and the current (I) passing through it, and then multiplying the two figures together to get the power P in watts (W) or kilowatts (1kW = 1000W), ie, P = V x I.

If the load uses power of say 2kW for one hour of time, we say it has used 2kWh (kilowatt-hours) of energy, which is equivalent to 7.2MJ. In other words, the energy used is found by simply multiplying the power in watts by the time in hours.

But in an AC (alternating current) system, things are more complicated. In an AC system both the voltage and the current are reversing in direction 50 (or 60) times per second. The graphs shown here are for a resistive load where the voltage and current are both sinusoidal, but this is not necessarily the case in reality.

Now, when the load connected to the AC power is purely resistive (such as a heating element), the current that flows through it will reverse in direction at exactly the same instants as does the voltage. This is usually described as the current being 'in phase' with the voltage, and you can see it in Fig. Ⓐ.



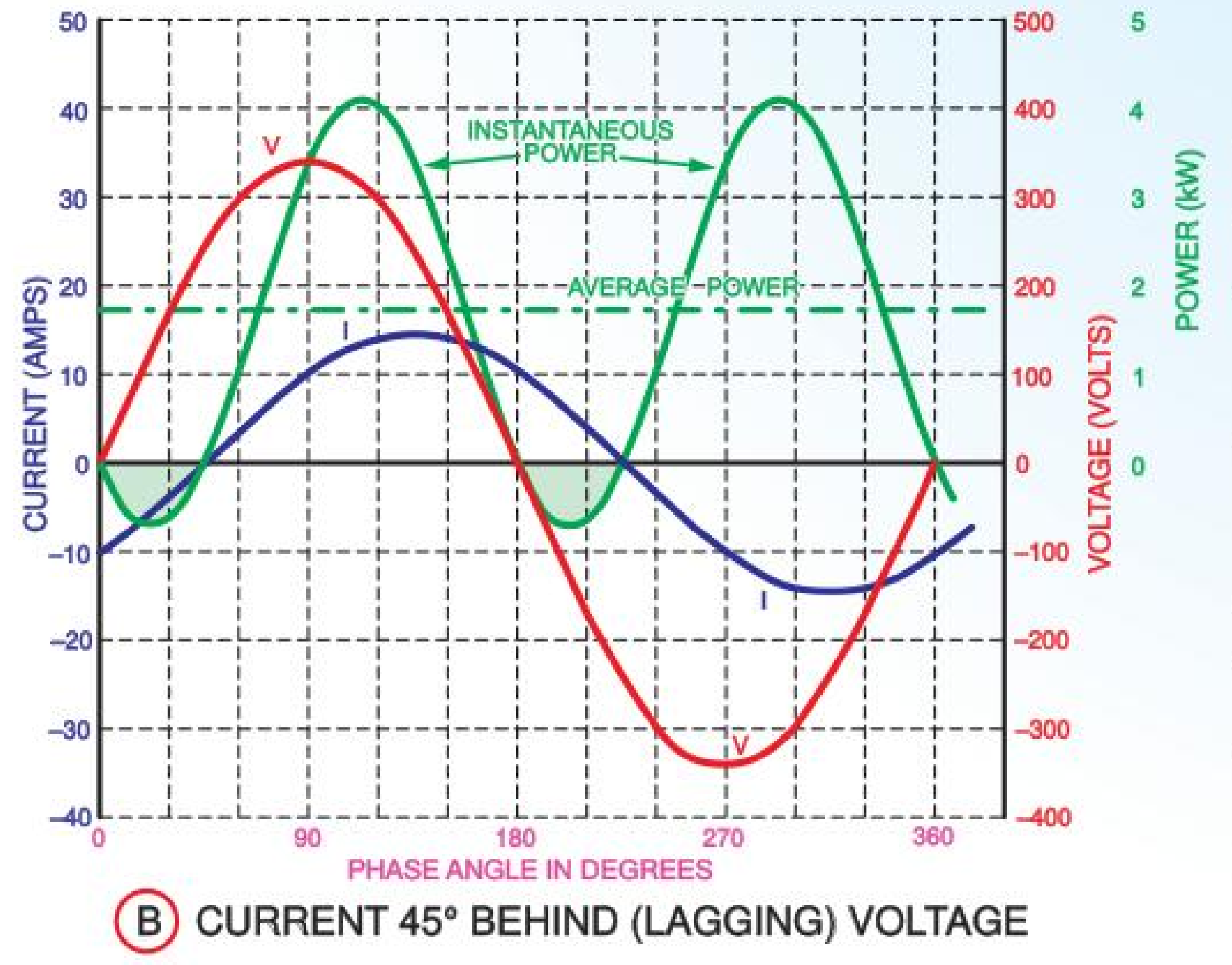
Ⓐ CURRENT IN PHASE WITH VOLTAGE

Since the power being consumed is again found by multiplying the voltage V and the current I together, this means that the power varies instantaneously with V and I. In fact, it varies in 'sine-squared' fashion, at a frequency of twice that of V and I, as shown by the solid green curve in Fig. Ⓐ. Note that this varying power is always positive.

The average heating effect of this rapidly pulsing power corresponds to a steady power level very close to the midway level of the power curve, as shown by the dashed horizontal line in Fig. Ⓐ.

The usual way of working out this 'real power' level when V and I are in phase is by measuring the RMS (root mean square) voltage and current, and then multiplying them together. So a heater element that draws 10A RMS from a 230V RMS mains supply would be consuming 10A x 230V = 2300W or 2.3kW.

It gets even more complicated in an AC system if the load is not purely resistive, but has a significant amount of inductance or capacitance. Examples of inductive loads include motors and fluorescent lamps. The effect of load inductance is to make the current 'lag' behind the voltage, while the effect of load capacitance is to make the current 'lead' the voltage.



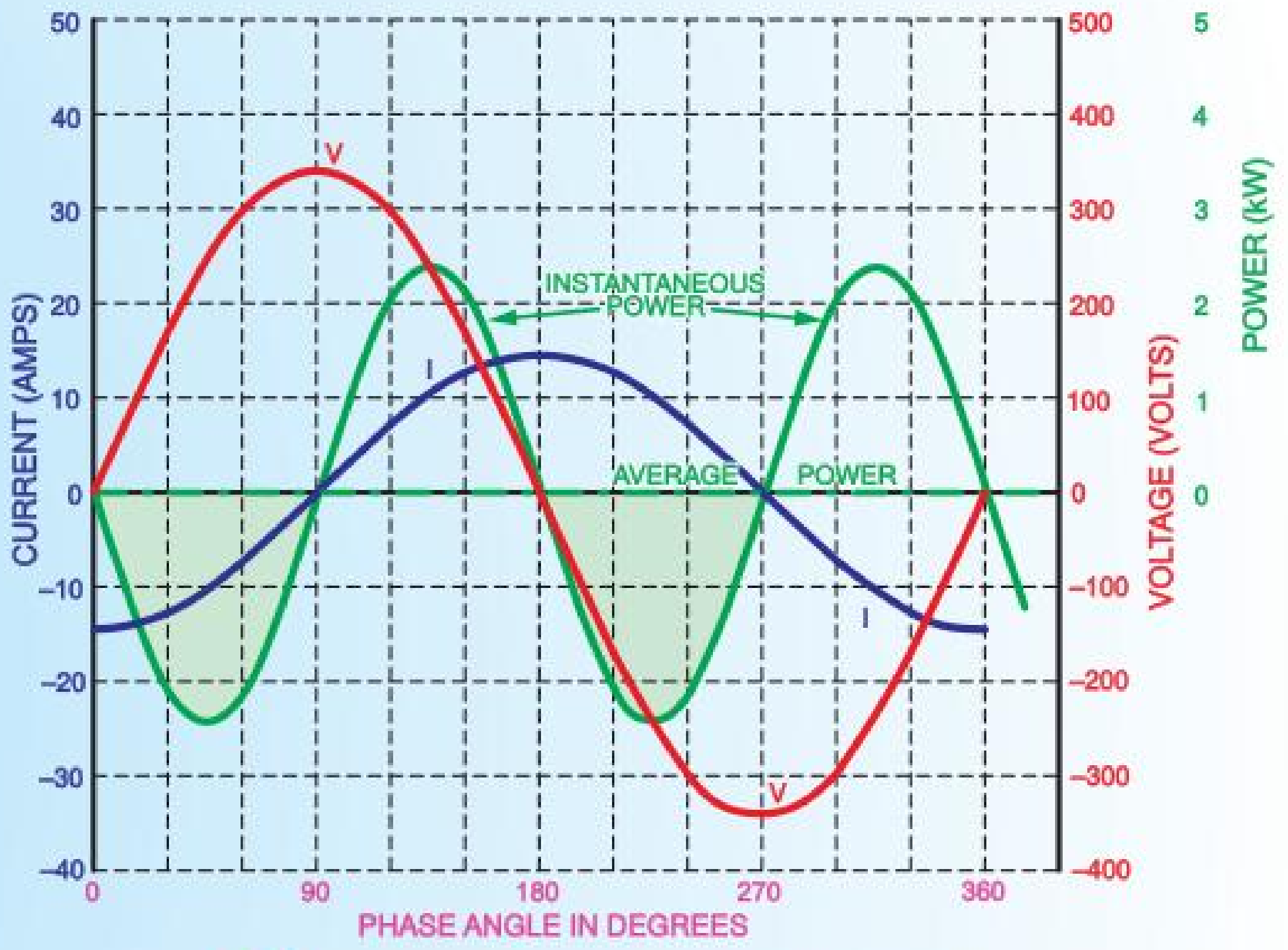
Ⓑ CURRENT 45° BEHIND (LAGGING) VOLTAGE

Fig. Ⓑ shows what happens when a partially inductive load causes the current to lag behind the voltage by 45°. This results in the instantaneous power curve (solid green) passing through zero and reversing in direction for part of each cycle (shaded areas). Can you guess what this means? It shows that power is actually being returned to the power company during these brief pulses. As a result, the real power being consumed by the load falls, as shown again by the dashed green line.

To work out the real power being dissipated by this kind of load, we need to multiply the RMS values of V and I together as before, but then multiply this result with a variable known as the 'power factor'. This takes into account the phase difference between V and I – ie, the degree to which the current lags or leads the voltage. In fact, it turns out that the power factor corresponds to the cosine of the phase angle 0. In other words, real power = V x I x cos 0.

Note that with a resistive load and no phase difference between V and I, the phase angle will be zero and the power factor is equal to cos(0) = 1. That's why the real power is equal to V x I.

In closing, consider the situation shown in Fig. Ⓒ, where the current is lagging behind the voltage by 90° – a full quarter cycle. As you can see, the instantaneous power curve swings above the zero axis for exactly half the time, and below the zero axis for the same amount of time (shaded areas). So the 'forward' and 'reverse' power flows effectively cancel out, and the average power drawn by the load is zero. Needless to say, the power companies are not happy with this type of load, because there is no billable power being consumed (cos(90°) = 0) – yet there is plenty of current flowing in their distribution system, so there will be energy lost in it.



Ⓒ CURRENT 90° BEHIND VOLTAGE

Is that it? Well, except for simple heating appliances like incandescent lamps, radiators and ovens, real-life loads are not purely resistive, or inductive or capacitive and they do not draw sinusoidal currents. So we need to take into account the widely varying current waveform shapes from all power supplies whether linear or switchmode, all lighting such as LEDs, fluorescent, CFLs and so on. And nor is the mains voltage waveform purely sinusoidal – it usually has the peaks clipped off due to the heavy peak currents drawn by capacitive-input power supplies and fluorescent lights.

To get over that problem and to accurately measure the RMS values of the voltage and current, the ADC needs to make samples of these parameters at a minimum of 2kHz and integrate the results. This means that the accuracy of the Appliance Energy Meter will not be affected by the shape of the voltage and current waveforms, provided that the harmonics do not exceed about 1kHz.

Mind you, the fact that voltage and current sampling needs to be made virtually continuously for reasonable reading accuracy greatly increases the workload of the Micromite because while it is sampling it still needs to update the displayed readings, respond to the touchscreen commands and so on.

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The sole fine-pitch SMD IC is the analogue-to-digital converter, IC2, as this is not available in any other package. Most of the other individual components are relatively large and easy to solder.

That's all for this month. In the second article we'll tell you how to build it, give more details on the Micromite software, explain how to calibrate it and also describe how it's used.

Thanks to Geoff Graham

Our thanks to Geoff Graham, the designer of the Micromite BackPack for his assistance during the development of this project.

Win one of two Microchip MPLAB PICkit 4 In-Circuit Debuggers

EVERYDAY PRACTICAL ELECTRONICS is offering its readers the chance to win one of two Microchip MPLAB PICkit 4 In-Circuit Debuggers (PG164140).

The Microchip MPLAB PICkit 4 In-Circuit Debugger allows fast and easy debugging and programming of PIC and dsPIC Flash microcontrollers, using the powerful GUI (graphical user interface) of the MPLAB X IDE (integrated development environment).

The MPLAB PICkit 4 programs faster than its predecessor with a powerful 32-bit 300MHz SAME70 MCU and comes ready to support PIC and dsPIC MCU devices. Along with a wider target voltage, the PICkit 4 supports advanced interfaces such as 4-wire JTAG and Serial Wire Debug with streaming Data Gateway, while being backward compatible with demo boards, headers and target systems using 2-wire JTAG and ICSP.

Key features of the PICkit 4 include matching silicon clocking speed, supplying up to 50mA of current to the target, a minimal current consumption of less than 100µA from the target, and an option to be self-powered from the target.

The MPLAB PICkit 4 is connected to the design engineer's computer using a high-speed USB 2.0 interface and can be connected to the target via an 8-pin SIL connector. The connector uses two device I/O pins and the reset line to implement in-circuit debugging and ICSP (in-circuit serial programming).

Currently, the MPLAB PICkit 4 In-Circuit Debugger/Programmer supports many but not all PIC MCUs and dsPIC DSCs, but it is being continually upgraded to add support for new devices.

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Trick your car's ECU with this . . .

ADJUST + 3 (<U)
LOAD 43<VIEW>

By John Clarke

Automotive Sensor Modifier

Using this *Automotive Sensor Modifier* you can change the signal response of many of your car's sensors to improve its driveability, throttle response, handling and so on. It allows you to modify and program the response of any voltage sensor in your car, without prejudicing reliability or affecting the ECU in any way.

MODERN CARS have lots of sensors to closely monitor the engine and other systems; they provide information to the ECU (engine control unit), which controls the fuel injectors and ignition timing, based on this information.

Some of the sensor outputs you can modify include the air flow meter, oxygen sensor, accelerometers (or G force sensors used in stability control and traction control), and the throttle position sensor (TPS). For cars with an electronic (drive-by-wire) throttle rather than a throttle cable, modification of the TPS signal can literally transform the way the car drives.

For example, you can alter the TPS signal so that there is less pedal travel required to provide more throttle. This will make the car 'feel' as though it has more power. And you can use this *Modifier* to restore correct air/fuel ratios after engine modifications, for preventing turbo boost cuts or to alter other sensor signals for improved driveability.

The *Automotive Sensor Modifier* described here is especially useful for adjusting a sensor output after engine modifications. The *Modifier* is then used to dial out the change in a sensor output due to the modification, to enable the engine to run correctly. In particular, various engine modifications or add-ons can cause a sensor output to go beyond the range normally expected by the ECU. This could cause it to issue an engine fault code that may result in the engine being set to run in limp-home mode. That means the engine and automatic transmission (if fitted) will be severely constrained until the fault code is cleared.

The *Automotive Sensor Modifier* takes a voltage signal and it can be programmed to produce a similar voltage at the output, but one which is shifted up or down in voltage level or changed in some other way. The programming is done using four pushbuttons in conjunction with a small LCD panel. Once the programming is done, the *Modifier* will do its job and the car will drive as you want it.

In a little more detail, the input voltage from the sensor is divided into 256 different levels called 'load sites'. Each load site can be independently programmed to alter the output by a set amount. The overall programming of all load sites is called a map. So as the sensor output changes in value, the output voltage from the *Automotive Sensor Modifier* will produce a modified voltage that follows the map.

Mapping is only one-dimensional, altering the output voltage according to a single input. This does have limitations compared to having two inputs, where for example, mapping can be for voltage from a sensor against engine RPM. But a single dimension interceptor is effective in many cases when altering the response from a sensor such as an engine MAP (manifold absolute pressure) or MAF (mass air flow) sensor.

This *Automotive Sensor Modifier* is simple to build, does not require a separate hand controller, and all controls and the LCD panel are on a single PCB.

Set up is simple and it is also easy to transfer the adjustments of one *Automotive Sensor Modifier* to a second unit. This is useful when building a second unit for an identical vehicle.

Features

An important feature of the *Automotive Sensor Modifier* is that when the map is set so that it produces no changes to the output, then the output exactly follows the input. That way, when you first connect the *Modifier* and before it is programmed, it will not affect the running of the vehicle in any way. Any subsequent changes introduced by programming the map values will smoothly alter the output.

Programming of the output mapping needs to be done with care and often in conjunction with equipment such as an air/fuel ratio meter to measure

the effect of any changes. Adding in wildly varying values could cause error codes issued by the ECU or worse, engine damage.

The input to the *Automotive Sensor Modifier* can range from 0-5V, but most sensors do not fully cover this voltage range. For example, a typical sensor output may only vary from 1.96V (minimum) to 4.65V (maximum). With the *Modifier*, you can set the input voltage range to be between the minimum and maximum sensor values. In doing this, the full 256 input load points are available for mapping.

The LCD shows both the current input load site number and the adjustment value that's set in the map. If there's no change, then the adjustment value for that load site is shown as 0. Changes to increase the output voltage are positive and changes to decrease the output voltage are negative.

Changes are made using the Up and Down switches, in one of two modes: (1) either in the Run mode (while the engine is running) as each load site is accessed in real time; or (2) in the View mode, where the load sites are accessed using the Left and Right switches.

Features and specifications

- Voltage input range: 0-5V
- Voltage output range: 0-5V
- Output adjustment: ±127 steps
- Output adjustment range: ±0.53V to ±5V (see Table 2)
- Adjustment resolution: 4.17mV to 39mV (see Table 2)
- Input adjustment points: 0-255 between the upper and lower input setting
- Upper input voltage limit: adjustable between 2.5V and 5V
- Lower input voltage limit: adjustable from 0V to the upper adjustment minus 2V
- Output adjustment response: typically 10ms to within 10% of the desired value
- Bypass relay: signal bypassed until the supply voltage rises by 0.5V from when power is first applied or the supply voltage exceeds 13.5V. Also switched by pressing the View/Run switch.
- Power Supply: 10-15V, 100mA

Circuit description

Fig.1 shows the circuit details. The two ICs used are a PIC16F88 microcontroller (IC2) and a quad op amp (IC1). The microcontroller monitors the sensor voltage and then produces a modified output according to the programmed map, in conjunction with quad op amp IC1. IC2 also monitors the switches and drives the LCD panel.

The sensor voltage is applied to the INPUT terminal of CON1 and then either directly through the normally closed relay contacts of RLY1a and RLY1b (when the relay is off) or in modified form via op amps IC1d-IC1a when the relay is switched on by the microcontroller.

The relay is included so that when the *Automotive Sensor Modifier* is first powered up (and when it's off), the input signal is bypassed around the *Modifier* circuit to the output. This is done so that the engine ECU will initially be directly connected to the sensor so as not to issue a fault code. This bypass mode allows the *Modifier* circuitry to start up and then produce the required output voltage.

IC2 monitors the battery voltage using a resistive divider at its AN4 input, pin 3. When power is first applied, it measures the voltage and stores the value. IC2 then continues to measure the voltage and when the supply reaches 0.5V above the stored value, the relay is switched on by IC2's RA6 output via transistor Q1 (the relay will also be switched on if the battery is above 13.5V). When the relay is on, the sensor signal is fed to op amp IC1d via an RC low-pass filter comprising a 100kΩ resistor and 1nF capacitor.

IC1d is configured as a unity-gain buffer and its output is fed to the AN1 input (pin 18) of IC2 via a 1kΩ resistor. IC2 converts the voltage to an 8-bit digital value and each digital value becomes a separate load site ranging from 0-255. Each site can then be mapped for an altered output.

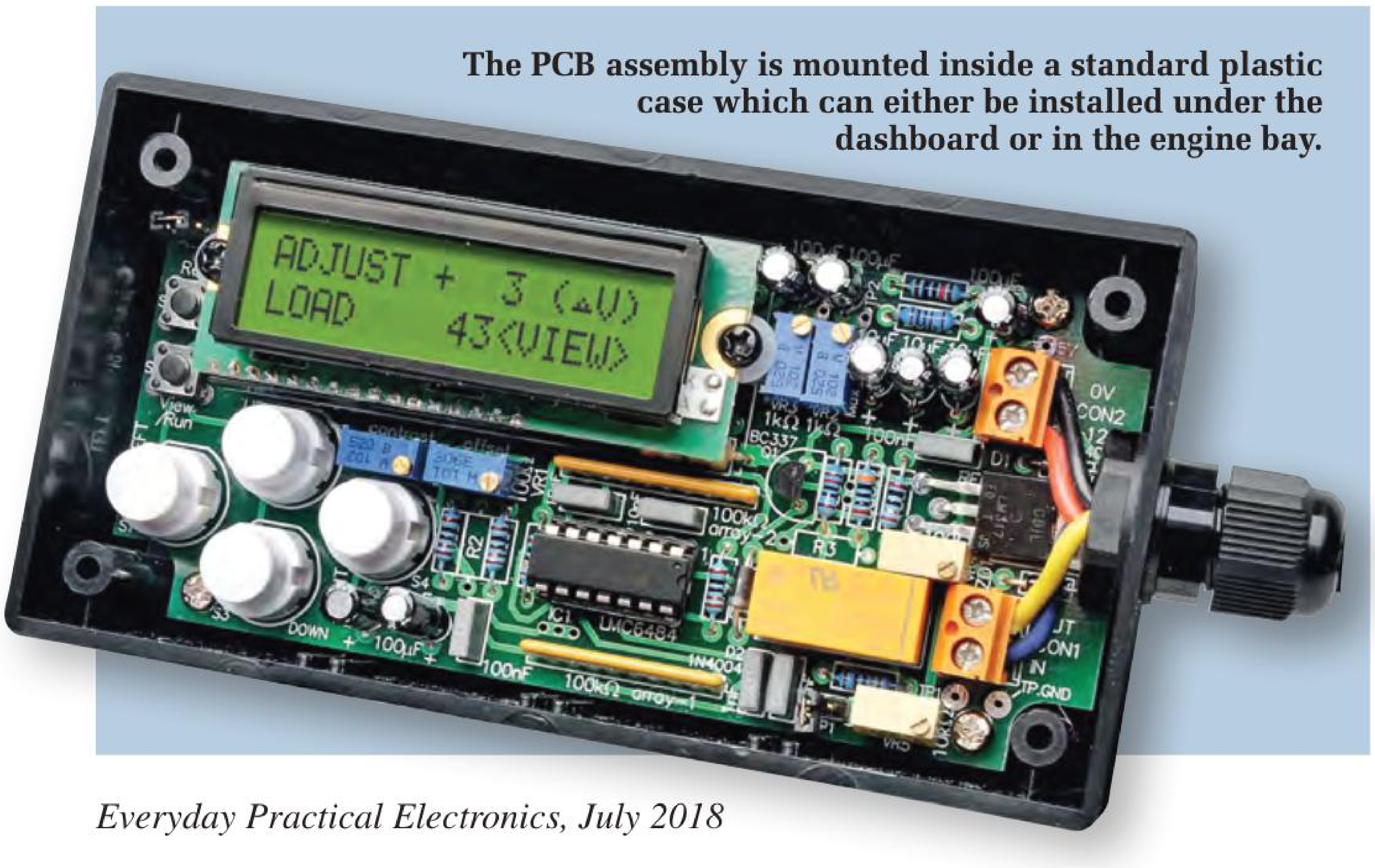
Note that there is also a jumper (JP1) that connects trimpot VR5 to provide a voltage which can be used instead of that from the sensor. This is applied when setting up and testing the *Automotive Sensor Modifier*.

The voltage at the AN1 input is fed to IC2's internal ADC (analogue-to-digital converter) and it has two references, REF+ and REF–, which are adjustable using trimpots VR2 and VR3.

There are limits in setting these two reference voltages. REF– can be set from 0V to 2V below REF+, while REF+ can be set between 2.5V and 5V. So for a sensor that has a 1.96V minimum and 4.65V maximum, REF– is set for 1.96V and REF+ set to 4.65V (these are within the voltage limit restrictions).

The next part of the circuit involving IC1c, IC1b and IC1a looks (and is) quite complicated, but we can simplify it in the following manner. Ignore IC1c and IC1b for the moment. Now the buffered output of IC1d is fed to an attenuator consisting of two series 100kΩ resistors and a shunt 100kΩ resistor. This attenuates the signal to one third the original level. The attenuated signal is then fed to op amp IC1a, which has a gain of 3, to make up for the loss in the attenuator.

So why go to the bother of attenuating and then amplifying the signal to bring it back to the original amplitude? The signal needs to be attenuated so it can be level-shifted by op amp IC1b, in response to a filtered PWM signal from pin 6 of microcontroller IC2. Without the attenuation, the level-shifted signal from IC1b would overload IC1a. Finally, IC1c is included to provide offset correction



The PCB assembly is mounted inside a standard plastic case which can either be installed under the dashboard or in the engine bay.

Parts list

1 double-sided, plated-through PCB, available from the *EPE PCB Service*, coded 05111161, 122 × 58.5mm
1 plastic case, 130 × 68 × 44mm
1 LCD module
4 pushbutton momentary contact switches (S1-S4)
2 tactile switches (S5,S6)
1 DPDT 1-5A 12V relay, RLY1
1 18-pin DIL IC socket
1 16-pin DIL IC socket (cut to form a 16-pin SIL socket for the LCD)
1 14-pin DIL IC socket (optional)
1 16-way SIL pin header
2 2-way pin headers, 2.54mm spacing (JP1 and JP2)
2 jumper shunts
1 cable gland for 3-6.5mm diameter cable
2 2-way screw terminal blocks, 5.08mm spacing (CON1,CON2)
4 M3 × 15mm tapped nylon spacers
9 M3 × 6mm pan head screws
4 M3 × 6mm countersink head screws
2 M3 × 9mm tapped spacers (to mount LCD)
2 M3 nylon washers (to mount LCD)
1 M3 nut
5 PC stakes (TP1-TP3, TP GND and TP5V)

Semiconductors
1 LMC6484AIN quad op amp (IC1)
1 PIC16F88-E/P microcontroller programmed with 0511116A.hex (IC2)
1 LM317T adjustable regulator (REG1)
1 BC337 NPN transistor (Q1)
1 16V 1W zener diode (ZD1)
2 1N0004 diodes (D1,D2)

Capacitors
5 100µF 16V electrolytic
3 10µF 16V electrolytic
4 100nF 63V MKT
2 10nF 63V MKT
1 1nF 63V MKT

Resistors (0.25W, 1%)
2 100kΩ 2% 10-pin SIL 5-resistor arrays (4610X-102-104LF) (RA1,RA2)
1 20kΩ
1 10kΩ
5 1kΩ
1 390Ω 1W
1 300Ω
1 150Ω
1 120Ω
1 10Ω
R1 – see Table 2

Trimpots
2 10kΩ multi-turn top-adjust trimpots (VR5,VR6)
2 1kΩ multi-turn top-adjust trimpots (VR2,VR3)
2 100Ω multi-turn top-adjust trimpots (VR1,VR4)

Where to buy parts

The programmed microcontroller for this design is available from the Silicon Chip Online Shop:
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for the inevitable shifts caused by the signal manipulation.

The amount of level shifting performed by IC1b (as varied by the PWM signal) is set by the value of resistor R1, which effectively forms a divider with the 100kΩ PWM filter resistor.

When R1 is 100kΩ, the output can be shifted by up to 5V in either direction. This means that a 0V signal can be shifted up to +5V, while a 5V level could be shifted down to 0V. There are some restrictions though. IC1a's output can only range from between 0V and 5V. So you won't be able to shift a 4V output beyond 5V. Smaller ranges of adjustment are available by using lower R1 values, and this also provides finer adjustment resolution. Table 2 shows the details.

Note that the red numbering used for the 100kΩ resistors around the op amps indicates a pair of precision 5-resistor arrays. So, for example, the 100kΩ resistor between pins 8 and 6 of IC1 is RA2,2 (red), meaning that it is the second 100kΩ resistor in the second resistor array, RA2.

Power supply

An LM317T adjustable 3-terminal regulator (REG1) provides power for the LCD module, IC1 and IC2 and for references REF+ and REF–. A 10Ω resistor and zener diode ZD1 protect the regulator's input from excessive voltage. REG1 has resistors connected to its OUT and ADJ (adjust) terminals so that the output can be adjusted to an accurate 5V using trimpot VR4.

The LCD module is driven by IC2 via its RA0, RA7 and RB4-RB7 outputs. These outputs go to data inputs DB4-DB7 of the LCD module, and to its enable (EN) and register select (RS) inputs.

Pushbutton switches are connected to IC2's RB5, RB6 and RB7 outputs. The RB2 and RB3 inputs are normally pulled high (to 5V) via internal pull-ups, and if any switch is closed, then one of the RB2 or RB3 inputs will be pulled low via the closed switch contact.

IC2 then checks to see which switch is closed. It does this by taking RB5, RB6 and RB7 low one at a time. The closed switch will show a low on either RB2 or RB3 when one of the RB5, RB6 and RB7 outputs is low. For example, when S1 is closed, the RB2 input will be low when RB5 is low.

Building it

Building the unit is straightforward since all parts, including the LCD, are mounted on a PCB, coded 05111161 (122 × 58.5mm) which is available from the *EPE PCB Service*. The assembly is housed in a plastic utility case (130 × 68 × 44mm) and the switches and LCD are low enough for the lid to be attached without needing any clearance holes.

This means that the case is sufficiently sealed to keep dust and debris away from the PCB. It also means that any adjustments to the circuit must be done with the lid off, but that's no great hardship since the adjustments are basically 'set and forget'.

Fig.2 shows the parts layout on the PCB. Begin the assembly by installing the resistors.

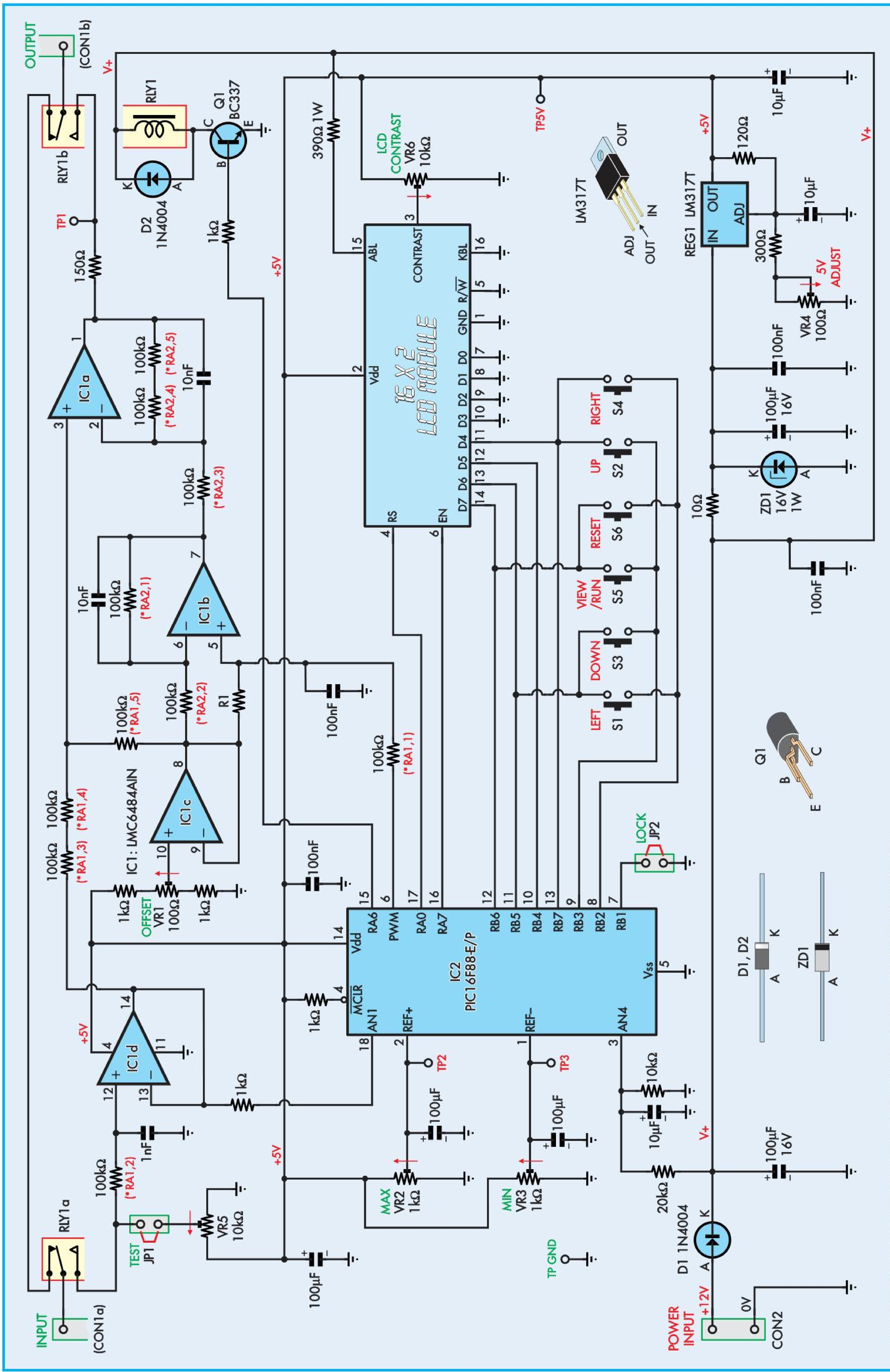
Diodes D1 and D2 (1N4004) can go in next, making sure they go in with the correct polarity. That done, install an 18-pin socket for IC2 with its notched end oriented as shown, then install IC1. The latter can either be directly soldered into place or mounted via a 14-pin socket.

Leave IC2 out of its socket for the time being; it's fitted later, after the supply rail has been checked.

Next, install 2-way pin headers for JP1 (bottom, right) and JP2 (top, left), then fit PC stakes to the five test points: TP1-TP3, TP GND and TP5V. The capacitors can then all go in. Note that the electrolytic types must all be oriented as shown on Fig.2.

Transistor Q1 (BC337) is next on the list, followed by regulator REG1. As shown, REG1 is mounted flat against the PCB with its leads bent down through 90° so that they go through their respective holes. The two outer leads will need to be bent down about 7mm from the regulator's body, while the centre lead is bent down some 5mm from the body.

Having bent the leads, drop REG1 into place and secure its metal tab to the PCB using an M3 × 6mm screw and M3 nut before soldering its leads. Note: the mounting screw can later be removed if it fouls the cable gland used to pass the external wiring connections when the PCB is later mounted in the case.



OUTPUT
(CON1b)
INPUT
(CON1a)
V+
RLY1
RLY1b
RLY1a
Q1 BC337
D2 1N4004
TP1
150Ω
1kΩ
IC1a
IC1b
IC1c
IC1d
IC1: LMC6484AIN
100kΩ
(*RA2,5)
(*RA2,4)
(*RA2,3)
(*RA2,1)
(*RA2,2)
(*RA1,5)
(*RA1,4)
(*RA1,3)
(*RA1,2)
(*RA1,1)
10nF
1nF
R1
OFFSET VR1 100Ω
TEST JP1
VR5 10kΩ
+5V
100μF
100nF
390Ω 1W
LCD CONTRAST VR6 10kΩ
16 X 2 LCD MODULE
ABL
CONTRAST
KBL
R/W
GND
Vdd
RS
EN
D0 D1 D2 D3 D4 D5 D6 D7
TP5V
LM317T
ADJ
OUT
IN
IC2 PIC16F88-E/P
MCLR
AN1
REF+
REF–
AN4
Vdd
Vss
RA6
PWM
RA0
RA7
RB6 RB5 RB4 RB7 RB3 RB2 RB1
TP2
TP3
MAX VR2 1kΩ
MIN VR3 1kΩ
TP GND
RIGHT S4
UP S2
RESET S6
VIEW /RUN S5
DOWN S3
LEFT S1
LOCK JP2
REG1 LM317T
120Ω
300Ω
5V ADJUST
VR4 100Ω
10μF
100μF 16V
ZD1 16V 1W
10Ω
10kΩ
20kΩ
D1 1N4004
POWER INPUT
+12V
0V
CON2
Q1
B C E
D1, D2
ZD1
A K

* RA1 & RA2 ARE EACH 5x100kΩ ARRAYS

AUTOMOTIVE SENSOR MODIFIER

Fig.1: the *Automotive Sensor Modifier* is based on PIC16F88-E/P microcontroller IC2, which has the ability to adjust a sensor's output at 256 points. The signal from the sensor is fed in via relay RLY1a, buffered by IC1d and fed to IC2's AN1 (pin 18) input. IC2 then produces a PWM signal at pin 6, which is then filtered and fed to IC1b to produce the programmed offset voltage. This is then fed to pin 2 of IC1a and then to the output terminal via relay RLY1b.

Trimpots and LCD header

Now for multi-turn trimpots VR1-VR6. VR1 and VR4 are both 100Ω and may be marked as 101, while VR2 and VR3 are 1kΩ types and may be marked as 102. Similarly, VR5 and VR6 are 10kΩ types and may be marked as 103. Be careful not to get the trimpots mixed up and be sure to install each one with its adjustment screw oriented as shown.

The single-in-line (SIL) 16-way pin header for the LCD module can now be installed on the PCB. Solder the two end pins first, then check that it's sitting flush against the PCB before soldering

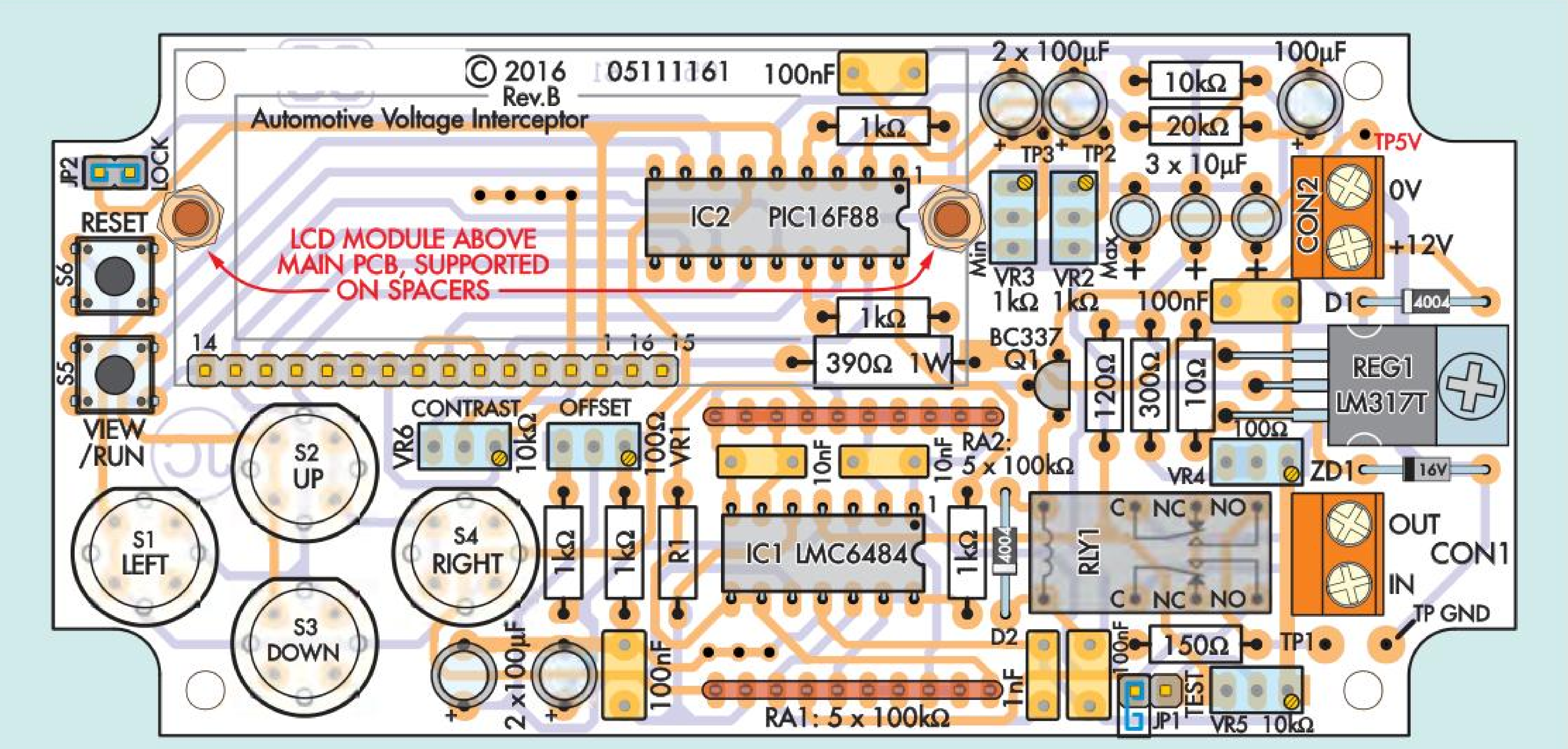


Fig.2: follow this parts layout diagram and the photo on the second page to build the PCB. The LCD module plugs into a 16-way pin header and is supported on two spacers. Make sure that all polarised parts are correctly oriented.

the remaining pins.

Once it's in place, mount a 16-way SIL socket on the underside of the LCD module (ie, with its pins soldered to the top of the module). This socket can be made by cutting a 16-pin (DIL16) IC socket in half lengthways and then mounting the two separate 8-pin sockets end-to-end on the LCD module.

Screw terminal blocks CON1 and CON2, relay RLY1 and the six switches can now be installed. Note that S1-S4 must be oriented as shown, with the flat edge of each switch towards the LCD module. S5 and S6 can be mounted on the PCB with the correct orientation only.

Installing IC2 and the LCD

Before installing microcontroller IC2 and the LCD module, it's necessary to accurately set the +5V rail. To do this, first apply power (12V DC) to CON2, then connect a multimeter between TP5V and TP GND and adjust trimpot VR4 for a 5.00V reading.

Now switch off and install IC2 in its socket. Make sure that its notched end is oriented as shown in Fig.2. The LCD module can then be installed by plugging it into the 16-way pin header and securing it to two M3 × 9mm tapped nylon spacers, with a nylon washer added to the top of each spacer.

Begin by securing the two M3 × 9mm spacers to the PCB using M3 × 6mm screws (see Fig.2). Do these screws up firmly, then plug the LCD module into the pin header, slide the two nylon washers into place (ie, on top of the spacers) and secure the assembly using two more M3 × 6mm machine screws.

Fitting it in the case

The PCB is mounted inside the case on four M3 × 15mm tapped nylon spacers. That's done by first using the PCB to mark out the mounting hole positions in the base, then drilling the holes to 3mm. It's best to use a 1mm pilot drill to start the holes, to ensure accuracy. The holes can then be enlarged to 3mm and countersunk using an oversize drill.

A hole is also required in one end of the case for the cable gland, positioned 12.5mm down from the top edge and centred horizontally. This hole should also be initially drilled to 3mm. It's then reamed out to around 12mm to accept the cable gland.

The PCB assembly can now be secured in position. First, attach the four spacers to the PCB using M3 × 6mm machine screws. The assembly can then be dropped into place and secured using four M3 × 6mm countersink head screws which pass up through the base.

Test and adjustment

Now, the test and adjustment procedure:

Step 1: apply power and check that characters appear on the display. If no characters initially appear, adjust contrast trimpot VR6 until characters do become visible.

Step 2: press and hold Reset switch S6 for four seconds until RESET is shown on the LCD. This resets the map, with all the adjustment values cleared to 0.

Step 3: install jumper JP1 and connect a multimeter between JP1 and TP GND. Adjust VR5 for a reading of 2.5V.

Step 4: connect the DMM between TP1 and TP GND and adjust VR1 so that TP1 is also at 2.5V.

Step 5: connect the DMM between JP1 and TP1 and adjust VR1 for a reading that's as close to 0V as possible, then remove JP1. Note: this adjustment sets the *Automotive Sensor Modifier's* output to follow the input.

Note also that any voltage applied to the input cannot by altered until the relay is switched on. When the unit is installed in a vehicle, the relay switches on when the battery voltage rises after the engine has been started, ie, as the alternator begins charging.

However, if you are testing the unit with a fixed 12V supply, this feature may not be convenient. In that case, the relay can be switched on by pressing View/Run switch S5.

Using it

As stated earlier, the LCD lets you view the input load sites and the corresponding output change values, as set by pushbutton switches S1-S4.

On the top line, the LCD shows ADJUST, followed by the adjustment value and either (ΔV) or LOCK. The ΔV stands for 'delta voltage' and indicates the voltage change made to the output. The bottom line shows the input load site.

The ADJUST value can be any number between –127 and +127, and is 0 when there is no change made to the output compared to the input. As previously stated, the voltage range depends on the value of resistor R1, as shown in Table 2. This means that R1 also sets the adjustment resolution (or voltage steps).

If LOCK is displayed instead of (ΔV), it means that lock jumper link JP2 has been installed. This prevents any changes to the adjustment values using the pushbutton switches.

If BYPASS is shown instead of ADJUST, it means that the relay is not switched on and so the modified signal is not being fed through to the output. Instead, the input signal is directly connected to the output. As a result, when BYPASS is shown, the ΔV symbol is replaced with 0V to indicate that the output hasn't been changed by the programmed adjustment value.

The lower line of the display shows LOAD and then a number from 0-255. Following that is either /RUN/ or <VIEW>. The LOAD number shows the current load site which is one of 256 possible sites evenly spaced between the minimum and maximum input voltages. The displayed load site has the corresponding adjustment value shown on the top line.

The RUN display shows input load sites in real time as they follow any input voltage variation. You can observe each load site by adjusting trimpot VR5 (if jumper JP1 is fitted).

The VIEW display doesn't show the input load sites as they vary in real time. Instead, the input load site is selected by the Left and Right pushbutton switches (S1 and S4). This allows the entire load site map to be viewed (and altered) by scrolling through each value.

The display is switched between the RUN and VIEW modes by pressing the View/Run switch (S5).

Up and Down switches

The Up and Down switches (S2 and S3) are used to change the adjustment value for each load site. Each single press of an Up or Down switch increases or decreases the value by one step. Holding a switch down results in the value changing by about four steps per second. After five value changes, the values increase or decrease in steps of five.

The Left and Right buttons change the load site when in the VIEW mode. As with the Up/Down switches, the step rate increases when a switch is held closed. These switches do not operate in the RUN mode.

Pressing and holding the Reset switch (S6) for two seconds immediately clears all load site adjustment values to 0. The display briefly shows RESET on the top line when the reset occurs.

Adjustment

Before adjusting the unit, you first need to determine the voltage range produced by the sensor whose output you wish to modify. That can be done by connecting a multimeter to the sensor's output and checking the voltages produced under various driving conditions. This should include a wide range of throttle and engine load conditions. Get someone else to do the driving while you keep a record of the minimum and maximum voltages produced by the sensor.

Next, connect a multimeter between TP2 and TP GND and adjust VR2 for a reading equal to the sensor's maximum recorded voltage. That done, connect the multimeter between TP3 and TP GND and adjust VR3 for a reading equal to the sensor's minimum voltage.

There are a couple of things to watch out for here: (1) TP2 must be set somewhere between 2.5V and 5V; and (2) TP3 must be between 0V and 2V below TP2. This means that TP2 must be set to at least 2.5V, even if the sensor's maximum output is below this. TP3 then must be set so that it is at least 2V below TP2, even if this is below the sensor's minimum output.

Installation

Installing the *Automotive Sensor Modifier* is relatively straightforward, since there are just four external connections. Two of these are for power (+12V and chassis earth), while the other two 'intercept' the sensor's output. The sensor's output is connected to the *Modifier*'s CON1 input, while the output from CON1 is connected to the sensor's ECU wire.

Note that the original sensor-to-ECU connection has to be broken for the *Modifier* to intercept the signal, ie, the unit is installed in series with this lead.

Use automotive connectors for all wiring attachments and be sure to use automotive cable for the leads. The +12V rail for the unit should be derived from the switched side of the ignition and a suitable point can usually be found in the fusebox. **The connection to the switched ignition supply should be run to the *Automotive Sensor Modifier* via a 1A inline fuse. Use a circuit which is switched on by the ignition but does not drop out during cranking.**

The best location to mount the unit is inside the cabin, so that it remains cool. If you do later install it in the engine bay, be sure to keep it well away from the engine and the exhaust system so that it is not unduly affected by heat. It can be secured in position using suitable brackets.

Programming adjustments

In order to make real-time adjustments, you first have to ensure that the mode is set to RUN. That's done by pressing switch S5. It's also important to remove the jumper shunt at JP1.

Note that any adjustments made will not take effect until the relay switches on and the word BYPASS is replaced by ADJUST on the LCD module.

Before going further though, a word of warning: using the *Automotive Sensor Modifier* could result in engine damage if the programming adjustments are not done carefully and methodically. *YOU HAVE BEEN WARNED!*

The best way to tune an engine using the unit is to set the car set up on a dynamometer and have a specialised engine tuner make the adjustments. Alternatively, you can make initial adjustments under actual driving conditions, using suitable instruments to monitor the performance. This is best done on a closed road, eg, a racetrack.

Be sure to get an assistant to drive the car for you while you make the programming adjustments and monitor the instruments. **On no account should you attempt to adjust the unit yourself while driving.**

An on-board diagnostics (OBDII) reader will enable you to monitor the performance. If you don't have one, you can purchase an ELM327 OBD reader cheaply on eBay, typically for less than £10 including postage. It plugs directly into your car's OBD socket (located near the steering column) and pairs with an Android smart-phone via Bluetooth (a Wi-Fi version of the ELM327 will be required to pair with an iPhone).

By installing a suitable app on the smart-phone (eg, Torque Lite for an Android device – **http://bit.ly/2KmhYZV** – you can monitor various engine sensors and performance parameters, as well as check for (and clear) fault codes. Note that while modern cars use the standard OBDII reader format, some older vehicles may require a specialised reader.

Changes are made at the load sites as appropriate using the Up and Down buttons to assign values. Note that the load site values are likely to change while making adjustments. To minimise this, try to maintain constant engine conditions during programming. The unit locks onto the input value selected when an Up or Down button is pressed so that the input load site will not alter during an adjustment, so take care to ensure that you don't drift too far off the input load site by changing the engine conditions.

Releasing the Up or Down button will show the current load site. At this stage, it isn't necessary to access every input load site to make changes. However, you must keep a record of any sites that are actually assigned a value of 0, since these must be left at 0 when you later interpolate between the adjusted load site values – see below.

After mapping has been completed, you may find that you are using only a small range of adjustment values. In that case, try reducing the value of resistor R1. This results in larger adjustment values and increases the adjustment resolution. Of course, any changes to R1 will require a complete remapping of the load sites.

After making adjustments, there will inevitably be load sites that were not accessed and changed. This is because there could be up to 256 individual sites that may need adjustment and so only a representative number of sites are usually adjusted.

Interpolating the values

Switching to the VIEW mode lets you check your mapping. You should have already noted those sites which were mapped at 0. Any outputs that have a number other than 0 are obviously sites that were changed.

The job now is to make changes to the unmapped sites that sit between the adjusted sites. This involves interpolating the values so as to smooth out the changes between adjacent adjusted sites. Basically, it's just a matter of calculating the value of each step. That's done by dividing the difference between two adjusted sites by the number of unadjusted sites between them plus one.

Table 2: Output adjustment range vs. resistor R1

Adjustment range	Adjustment resolution	R1
±5V	39mV	100kΩ
±4.05V	31.9mV	68kΩ
±3V	23.6mV	43kΩ
±2.48V	19.5mV	33kΩ
±2V	15.7mV	24k
±1.3V	10.2mV	15kΩ
±1V	7.87mV	11kΩ
±0.697V	5.49mV	7.5kΩ
±0.53V	4.17mV	5.6kΩ

ELM 327 MINI
Interface
Supports all OBDII protocols

An ELM327 OBD reader paired with an Android smart-phone or tablet can be used to help set up the unit. A Wi-Fi version will be required to pair with an iPhone or iPad.

For example, Tables 3 and 4 show the initial mapped values and the result after manually interpolating the values. In Table 4, load sites 10, 11, 12 and 13 have values of 30, 0, 0 and 12 respectively. The difference between the two adjusted sites is 18 (30 – 12) and there are two unadjusted sites between them. In this case, we divide 18 by 3 (ie, 2 + 1) and this gives a step value of 6.

As a result, load sites 11 and 12 would be changed to 24 (30 – 6) and 18 (24 – 6) respectively, as shown in Table 5.

Similarly, for load sites 14 to 17, the output values are interpolated from an 8 at site 14 to a 0 at site 17. Note that site 17 was one that was mapped as a 0 and so this remains at 0. If the result of the divsion isn't a whole number, keep the decimal places and round the result for each load site to the nearest integer.

Finally, when mapping has been completed, the Lock jumper link can be installed on JP2 to prevent any further changes. If you are completely satisfied with the mapping, the LCD module can then be removed from the PCB.

Modifying sensor outputs

As stated, the unit can be used to modify any sensor that has an output ranging from 0-5V. In particular, this includes MAP and MAF sensors, but an exception here is the Karman Vortex air flow sensor, as this produces an output frequency rather than a voltage.

Typically, you would use the unit to modify a sensor's output to improve engine response or performance, or simply to prevent engine fault codes occurring. You will need a separate unit for each sensor you wish to modify.

Most of the time, an engine runs in what is called 'closed loop'. This is where the MAF (or MAP) sensor and the oxygen sensors are monitored so that the correct amount of fuel is delivered to the engine via the injectors.

In operation, the oxygen sensor acts as a feedback sensor to let the ECU know whether the engine is running rich or lean. This means that it's possible to make changes to a sensor's output but then find that there's no change in engine response. That's because the ECU is receiving feedback from the oxygen sensor and adjusts the injector signal accordingly to provide the air/fuel ratio required.

Basically, the ECU has a set of maps for each engine sensor and for the throttle position sensor and the injectors. These are just tables of expected sensor outputs against engine RPM, temperature, load and mixture. When the engine is running, the ECU compares the sensor maps against the actual sensor values. However, over time, the ECU makes some changes to the map (called trims) that are based on real-time engine running.

Table 3: Mapped and unmapped values

ΔV	30	0	0	12	8	0	0	0*	0
Load site	10	11	12	13	14	15	16	17	18
0* = load site mapped at 0; 0 = load site left unmapped									

Table 3: initial values for load sites 10-18. The load sites with a value of 0 (ie, 11, 12, 15, 16 and 18) were left unmapped, while load site 17 was mapped at 0.

Table 4: Values after interpolation

ΔV	30	24	18	12	8	5	2	0	0
Load site	10	11	12	13	14	15	16	17	18
Interpolated values shown in red – see text									

Table 4: the load site values after interpolation. The interpolated values are in red.

OK, let's take a look at some of the changes you can make.

1. Changing the oxygen sensor signal

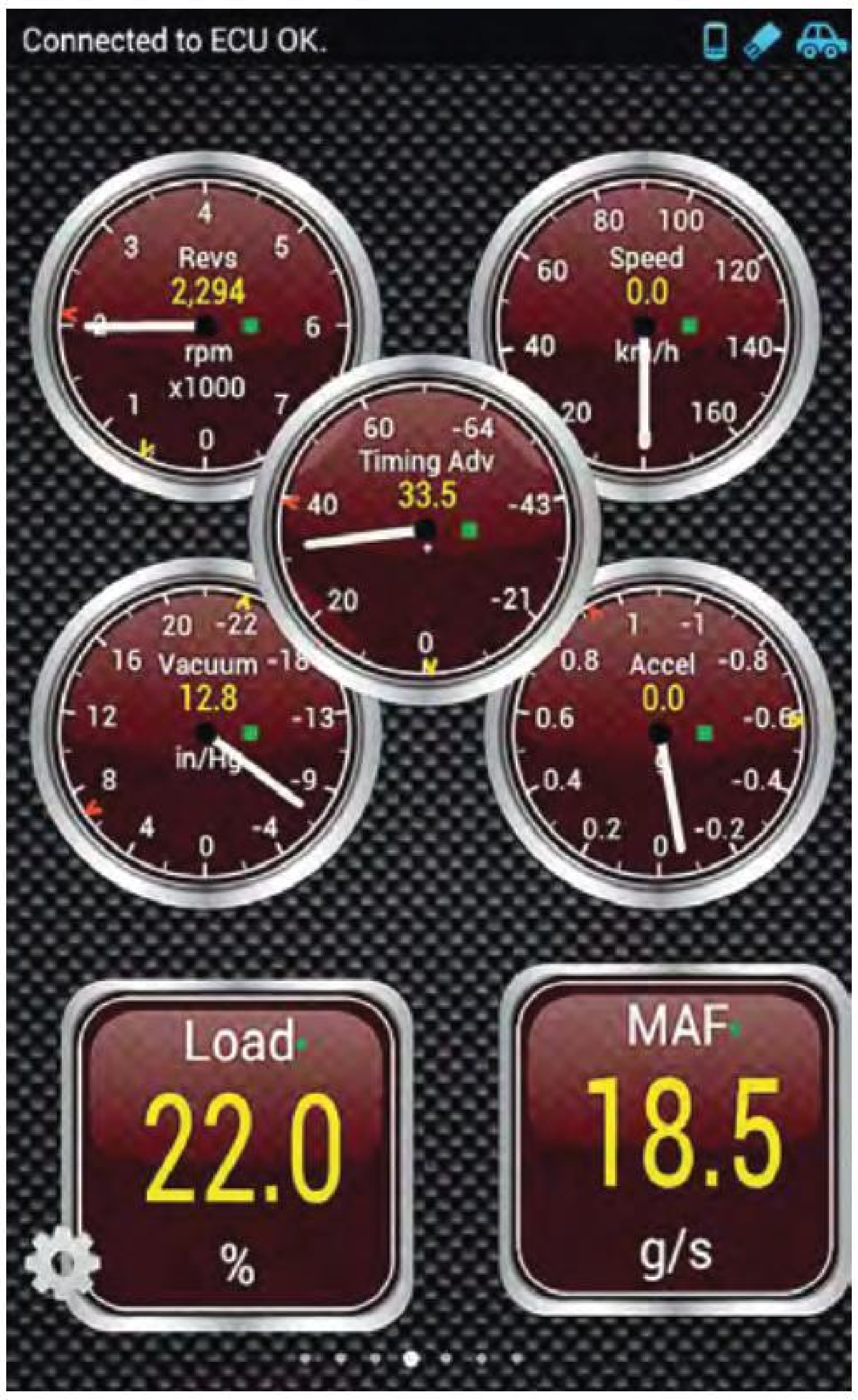
When an oxygen sensor is working correctly, it will provide the ECU with accurate air/fuel ratios. The ECU then modifies the injector duty cycle to match the oxygen sensor's signal and the signals from other sensors, to give the desired air/fuel ratio.

It's unlikely that a narrowband oxygen sensor signal can be successfully modified, mainly because the sensor signal appears more like a switch, as it produces a sharp change in voltage between lean and rich air/fuel ratios about stoichiometric. The output of a wideband oxygen sensor is also difficult to modify, because the sensor's expected output is determined internally by the ECU.

Note that a faulty oxygen sensor will be flagged if the injector and MAF (or MAP) sensor maps fail to correlate with the oxygen sensor's signal. This means that if you make changes to the output that go beyond what is expected by the ECU, then an error code will be issued. This not only applies to the oxygen sensor, but to other sensors as well.

2. Changing air/fuel mixtures

As well as operating in closed-loop mode, many engines also operate in open-loop mode under some conditions, during which the oxygen sensor is not monitored. This usually occurs at or near full throttle when the mixture is made richer to provide extra engine cooling. Adjusting a sensor



Running the Torque Lite app on an Android smart-phone paired with an ELM327 lets you monitor a wide range of engine parameters. This screen grab shows just some of the gauges that can be displayed.

output, such as from a MAF, will result in mixture changes under such conditions, with corresponding changes to engine performance.

You will need to make before and after modification measurements to ensure that the engine will not be running too lean or rich. If the mixture is set too lean, the engine could run too hot and damage the valves and pistons. Conversely, running an engine too rich can foul spark plugs, damage catalytic converters and cause pollution.

3. Reducing turbo boost cuts

Another possible use of the unit is to restrict the MAF (or MAP) sensor's output under high loads to prevent turbo boost cut. You will need a boost gauge to correctly carry out this modification.

It's just a matter of using the unit to alter the MAF's signal so that the ECU no longer reduces the boost above certain engine loads. By using the boost gauge, the load points where the boost is cut can be determined and the output from the *Sensor Modifier* reduced to eliminate the boost cut as required.

4. Throttle Position Sensor (TPS)

Electronic or drive-by-wire throttles (as distinct from cable-operated throttles) can be modified to alter the way a vehicle responds to throttle changes. This can radically change the way the car drives.

Using the unit to increase the throttle voltage at low-throttle positions can make the engine appear to have better response, especially from a standing start. Conversely, on more powerful vehicles, reducing the throttle voltage at low-throttle positions can make the vehicle more docile. This could be especially helpful when moving off in slippery conditions, where wheel-spin could otherwise easily occur.

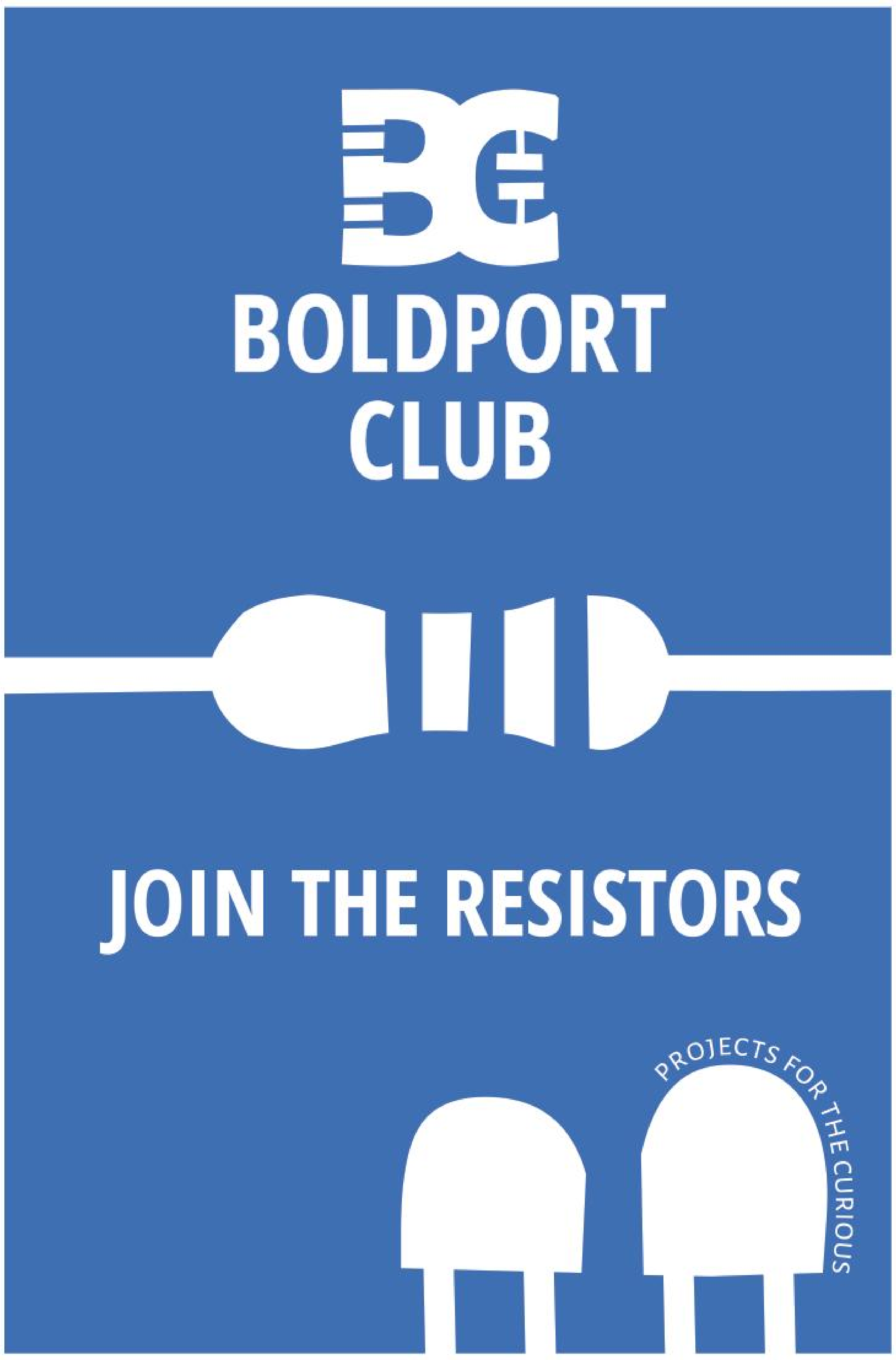
5. Injector changes

When larger-than-standard injectors are fitted, the unit can be used to reduce the air flow meter's output so that the correct air/fuel mixture ratios are maintained. Reducing the air flow meter's output will thus allow the ECU to operate within its normal range of input values, so that it can control the injector duty cycle and maintain correct mixtures.

6. Air flow meter changes

Installing a larger air flow meter results in lower air flow readings compared to the original unit. The *Sensor Modifier* can be used to restore the signal to the normal range of values expected by the ECU.

Finally, when you have completed mapping, don't forget to install the Lock jumper link at JP2.



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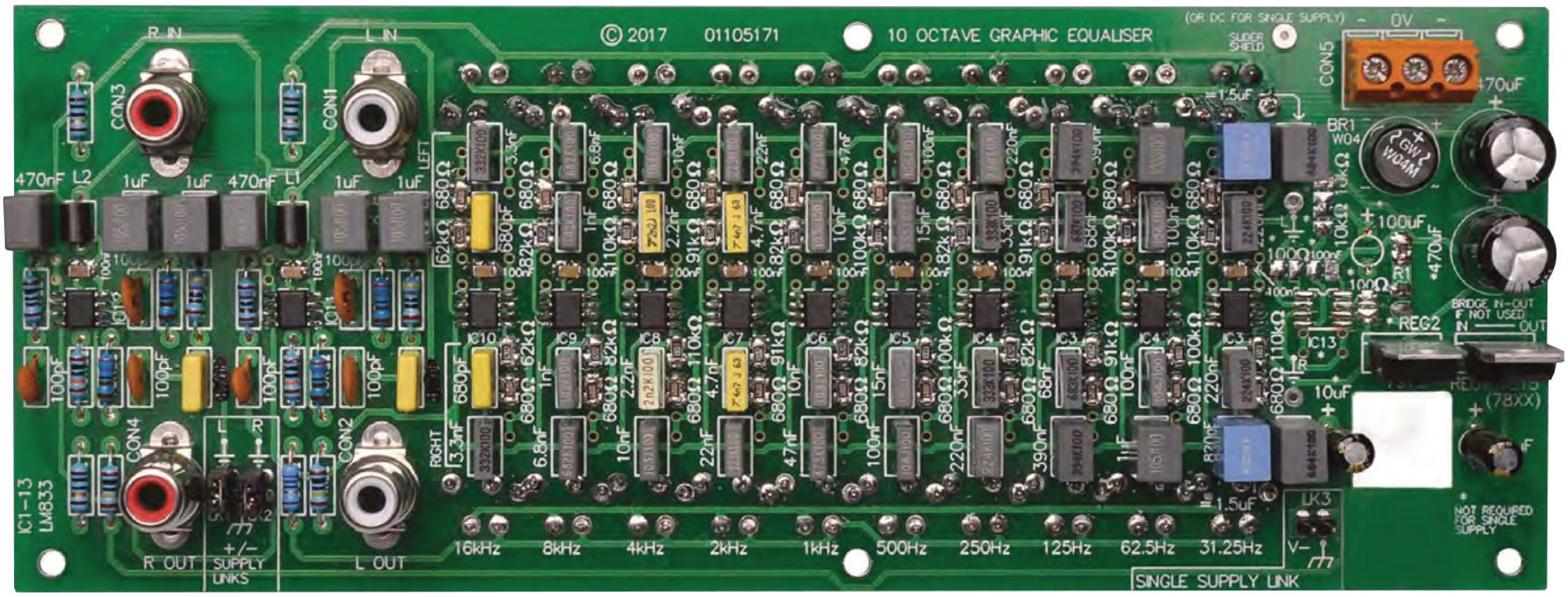
Part 2

By JOHN CLARKE

Last month, we described the circuit and performance of our new 10-octave Stereo Graphic Equaliser. Now we conclude with assembly details of the PCB and the acrylic case with its smart front panel.

For such a large circuit, the double-sided PCB for this project is surprisingly compact at only 198 × 76mm. It is coded 01105171 and can be purchased from the *EPE PCB Service*. It is very compact because we have mounted the 10 ganged slider pots on one side and all the active circuitry, with 12 (or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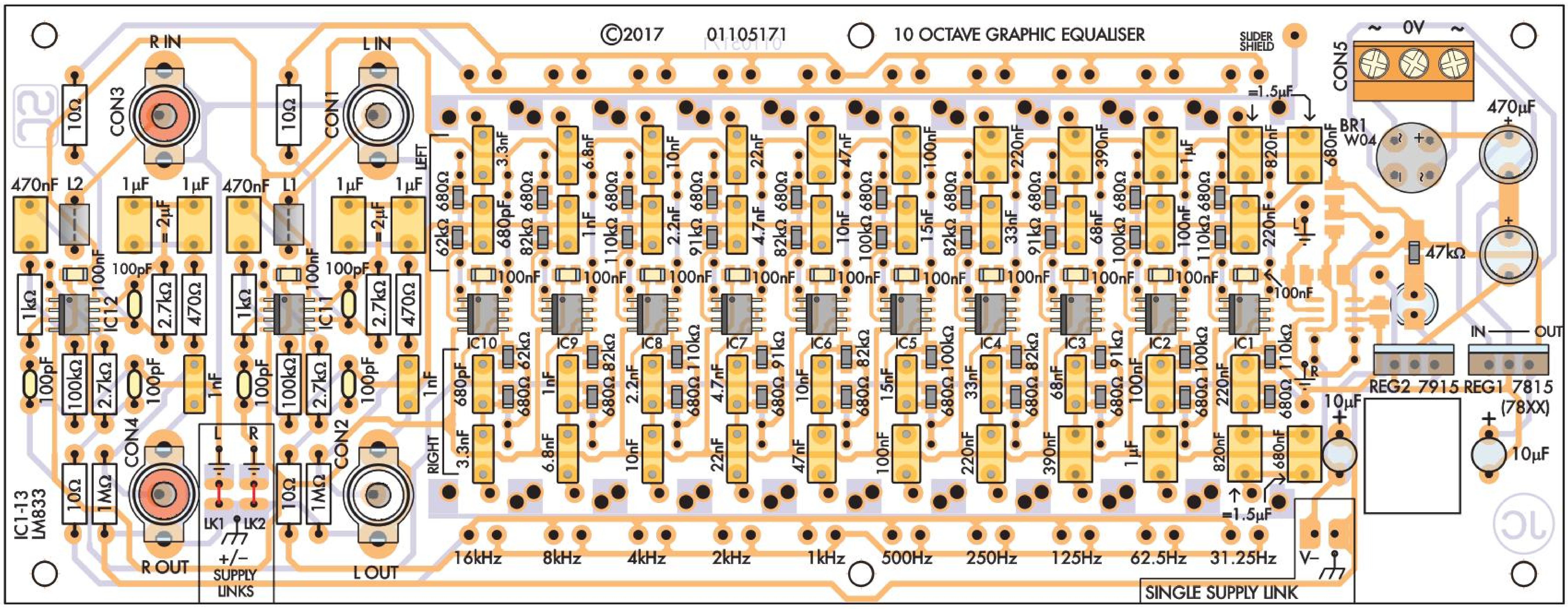
01105171
10 OCTAVE GRAPHIC EQUALISER
R IN
L IN
CON1
CON2
CON3
CON4
CON5
R OUT
L OUT
+/- SUPPLY LINKS
SINGLE SUPPLY LINK
IC1-13 LM833
16kHz
8kHz
4kHz
2kHz
1kHz
500Hz
250Hz
125Hz
62.5Hz
31.25Hz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01105171
10 OCTAVE GRAPHIC EQUALISER
SLIDER SHIELD
0V
CON5
BR1 W04
470µF
47kΩ
REG2 7915
REG1 7815 (78XX)
IN
OUT
10µF
R IN
L IN
CON1
CON2
CON3
CON4
LEFT
RIGHT
IC1
IC2
IC3
IC4
IC5
IC6
IC7
IC8
IC9
IC10
IC11
IC12
IC1-13 LM833
LK1
LK2
+/- SUPPLY LINKS
R OUT
L OUT
=1.5µF
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SINGLE SUPPLY LINK

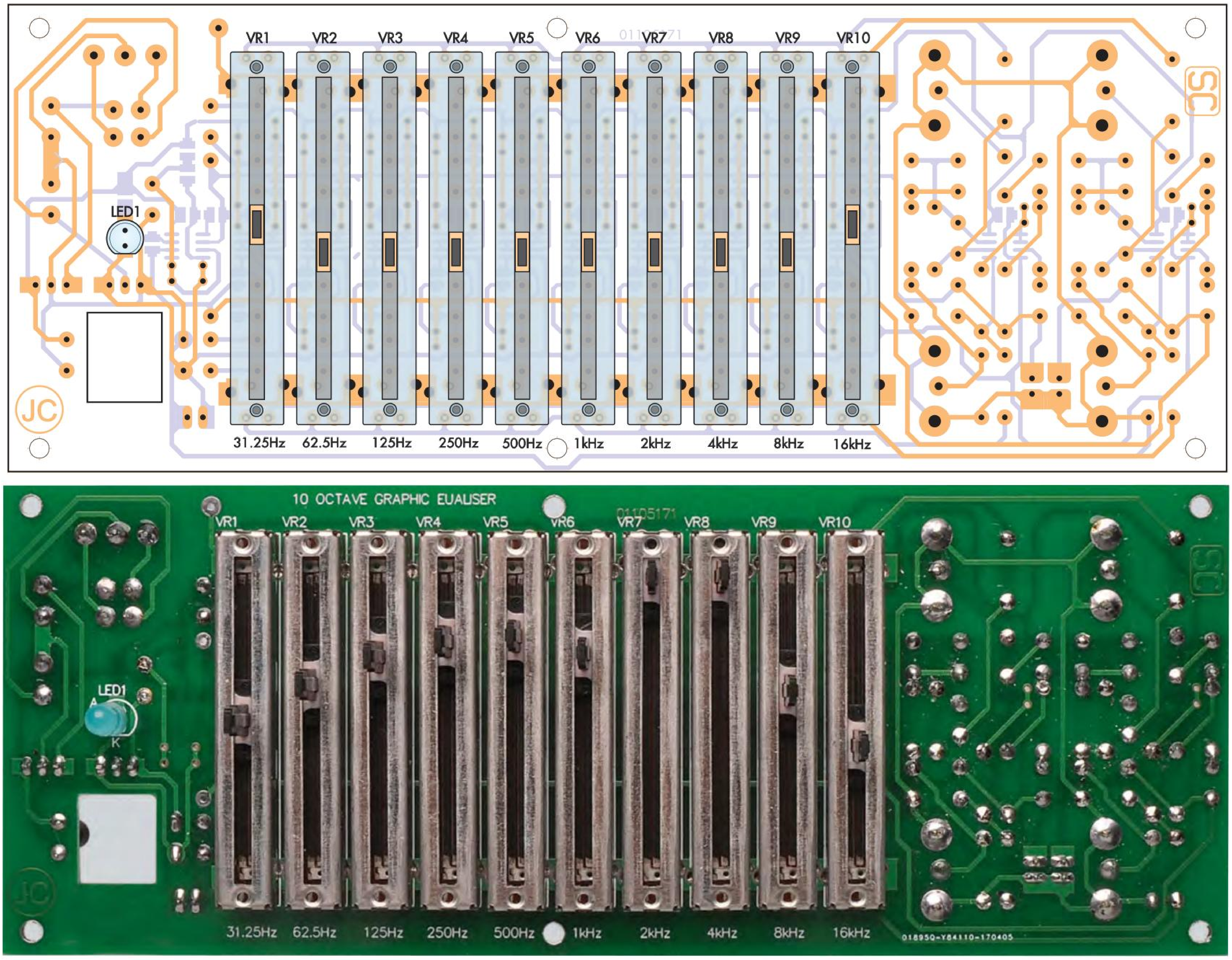


Fig.8: the top side of the PCB contains only the 10 slider pots and the power LED; everything else is on the underside. Again, the matching (same size) photo at right will assist you in PCB assembly. The square hole in the board is to accommodate the power switch, itself attached to the front panel.

13) LM833 low-noise dual op amps, on the other side.

Virtually all of the resistors are surface-mount types, but fortunately you can read their printed values (with a magnifying glass!).

All of the capacitors, apart from 12 (or 13) 100nF surface-mount ceramic bypass caps, are through-hole types, so while some components are quite small, they are also quite straightforward to solder in place.

Fig.7 (left): use this component overlay (and the matching photo at right) if you want to use an AC supply. It contains the bridge rectifier, smoothing capacitors and most importantly the positive and negative 15V regulators. Note also the supply links (top left) – both are in place. In the photo these are shown as header sets but as these would normally be set once and forgotten, wire links (from component lead offcuts) would be the way to go.

And the benefit of soldering the surface-mount components is that you don't have to clip off their pigtails after soldering.

The PCB front panel shown in the prototype above left is a little smaller than the acrylic case but we have since modified it so that the outside dimensions of the front panel and case are the same – it looks neater.

Mind you, the acrylic case is not needed if the equaliser is to be mounted into existing equipment or into a half-rack-width 2U case – but you will still need some form of front panel.

Choice of supplies

We have provided two component overlays for the PCB, one for the AC-powered version and the other for the DC-powered version. The main difference is that the DC version omits the components for the low-voltage AC power supply, but adds the circuit components associated with IC13, as depicted on page 24 of last month's issue (June 2018).

To assemble the PCB, you will need a fine-tipped soldering iron bit, 0.71mm-diameter solder, a good light and a magnifying glass or spectacles to be able to solder the surface-mount components in place.

Begin by mounting the surface-mount ICs. As already noted, IC13 is only installed if you intend to use a DC supply.

Each IC is first oriented correctly and note that the chamfered side is the pin 1-4 side of the IC. Place the IC in position over the PCB pads and solder one corner pin. Check its alignment and remelt the solder if the IC needs adjustment. When the IC is aligned correctly, solder the remaining seven pins. Make sure that there

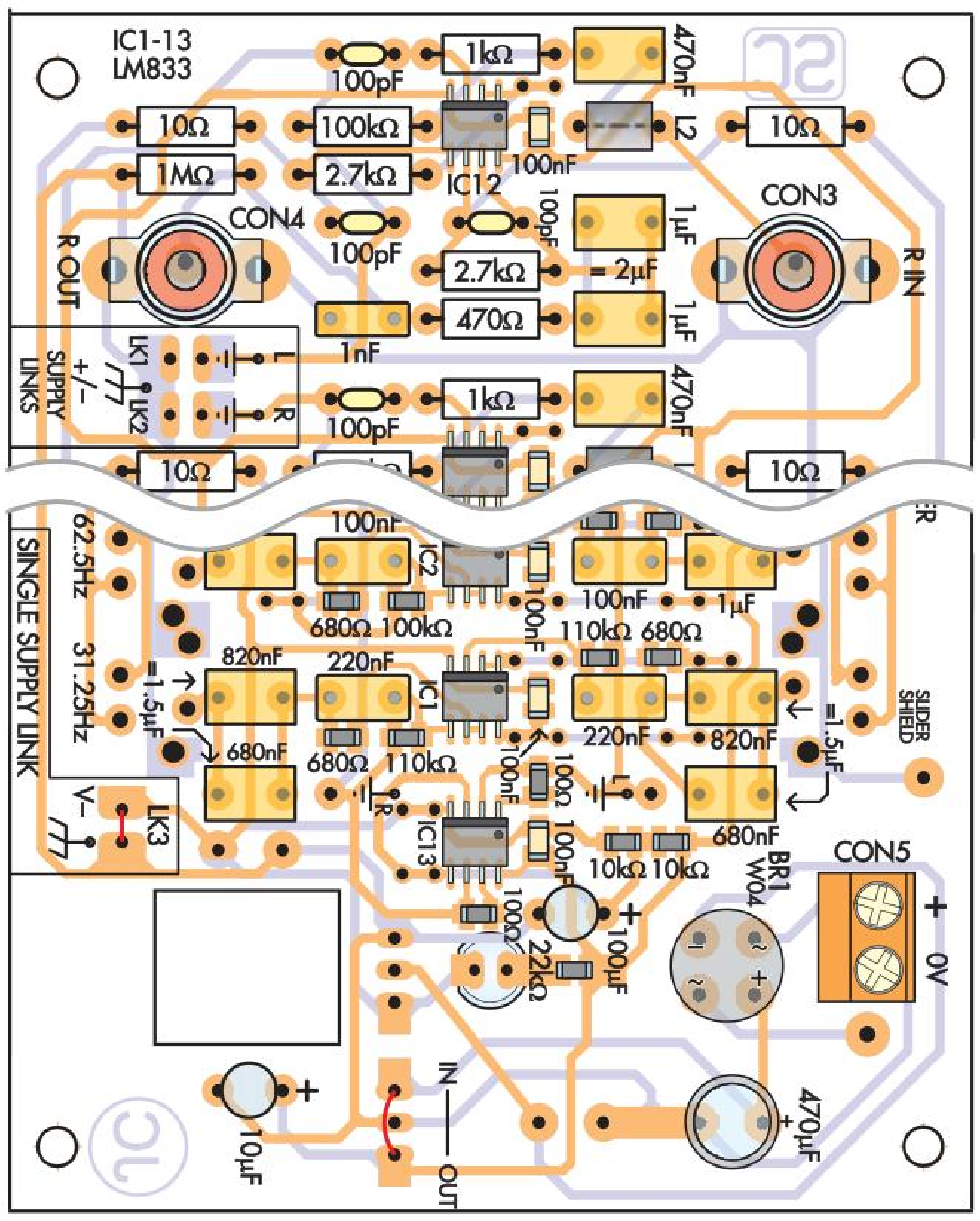
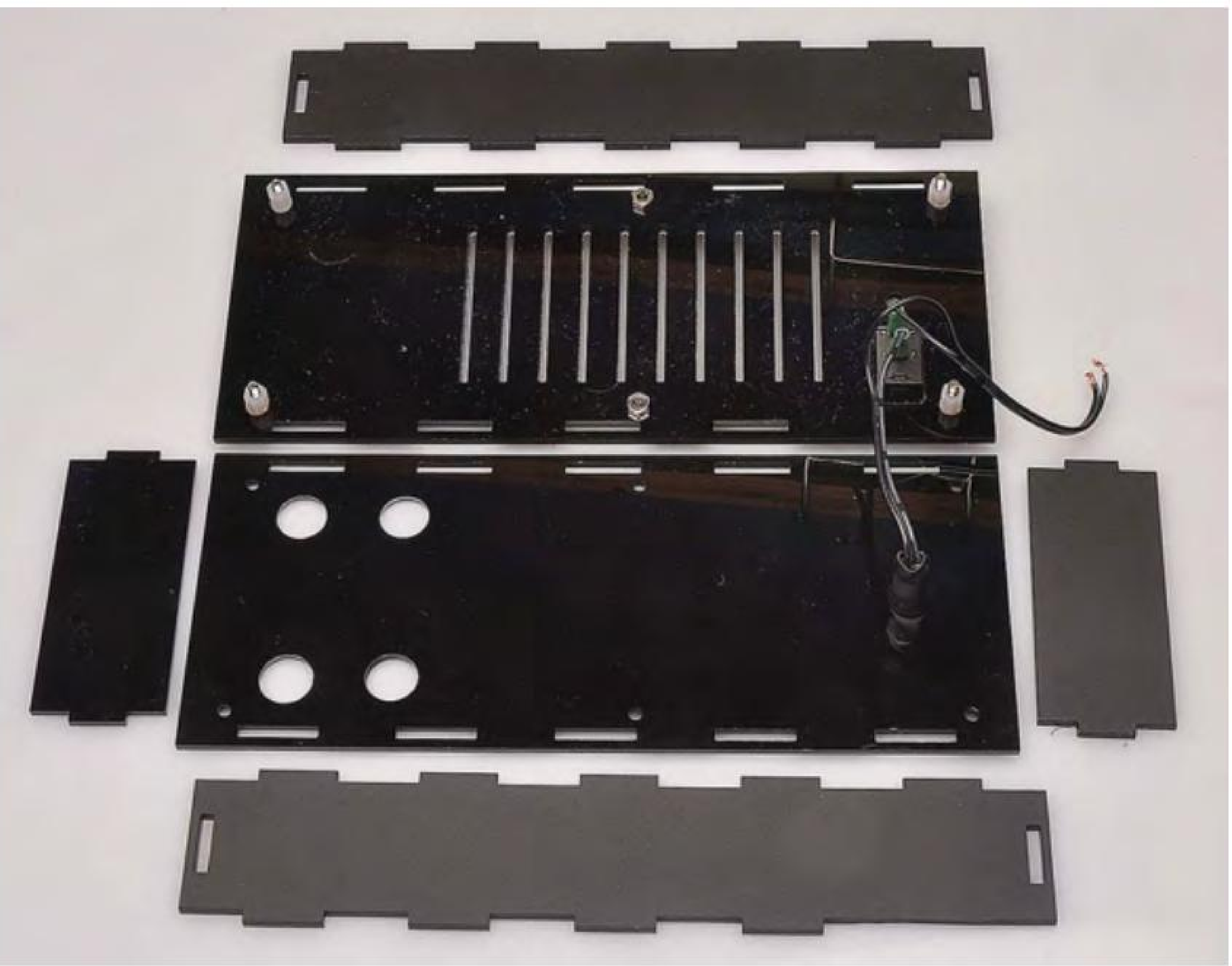


Fig.9: use this alternative PCB overlay if you are using a DC supply. Only the two end sections of the PCB are shown – the centre of the PCB is identical. Note the absence of links for LK1 and LK2 but the link over three pads at the bottom (this would be easiest achieved on the underside of the board).



The low cost and ease of assembly of our new *Graphic Equaliser* is due in no small part to the laser-cut 'case', shown here with the power switch and DC supply socket fitted.

are no solder bridges across any of the adjacent pins.

Then align and solder the 100nF supply bypass capacitors for IC1-IC12 (and for IC13 if used). Then the surface-mount resistors can be soldered in place including that for LED1 and those resistors used for the DC version, if that is the version being built.

We said that the surface-mount resistors have the values printed on them, but some 'interpretation' is required. A 3 or 4-digit code is used, with the last digit being the number of zeros. So the 680Ω resistors will be labelled 6800, ie, 680 with no extra zeros. The 100kΩ resistors will be 100, with three zeroes, ie, it is labelled as 1003.

Once all the surface-mount components have been installed, the through-hole components can be mounted. Start with the resistors and then fit the two ferrite beads, using a resistor lead offcut to feed through each bead before you solder them in place.

Then install the MKT polyester capacitors. Note that the 820nF and 680nF capacitors for the 32Hz gyrator are connected in parallel to make up a value of 1.5µF. Alternatively, you could use 1µF and 470nF capacitors instead, if the 680nF and 820nF values prove difficult to obtain.

The electrolytic capacitors are mounted next, taking care to orient each one with the correct polarity.

When mounting the RCA sockets, the white ones are for the left channels and the red are for the right channels. The 3-way screw terminal CON5 is mounted with the opening to the edge of the PCB.

Take care when mounting the bridge rectifier by making sure that its pin labelling matches the screen printing on the PCB. REG1 (and REG2 if used) can be installed next, seated as far down onto the PCB as they will go.

For the DC supply version, you can use a 15V regulator (7815) if the DC source is between 18V and 25V (maximum). If the supply is less than 18V, a 12V regulator (7812) can be used, provided the DC input is 15V or more.

Below this 15V, you can dispense with the regulator and connect a wire link between the IN and OUT terminals; the two outer pads for the component).

Naturally, this will mean the supply is unregulated.

Headers LK1 and LK2 or LK3 can be installed next. LK1 and LK2 are for the AC version and LK3 for the DC version. Install the jumper links on LK1 and LK2 for the AC powered version and a jumper link on LK3 for the DC version.

That should complete all the components installation, apart from the 10 sliders and LED1, which are mounted on the other side.

So it is most important that you carefully check that you have installed and soldered all the parts correctly before moving on to the next stage (with the sliders).

In particular, double check parts placement for the capacitors that mount directly opposite the sliders. Once the sliders are installed, you will not have access to the soldered connections for any of these capacitors.

Before mounting the sliders on the front of the PCB, make sure that all of the capacitor leads that were soldered on this side of the PCB have been trimmed back.

This must be done so that the sliders can be fully seated onto the PCB.

Note that the sliders only fit with one orientation. So if they don't seem to fit, try the alternative 180° orientation.

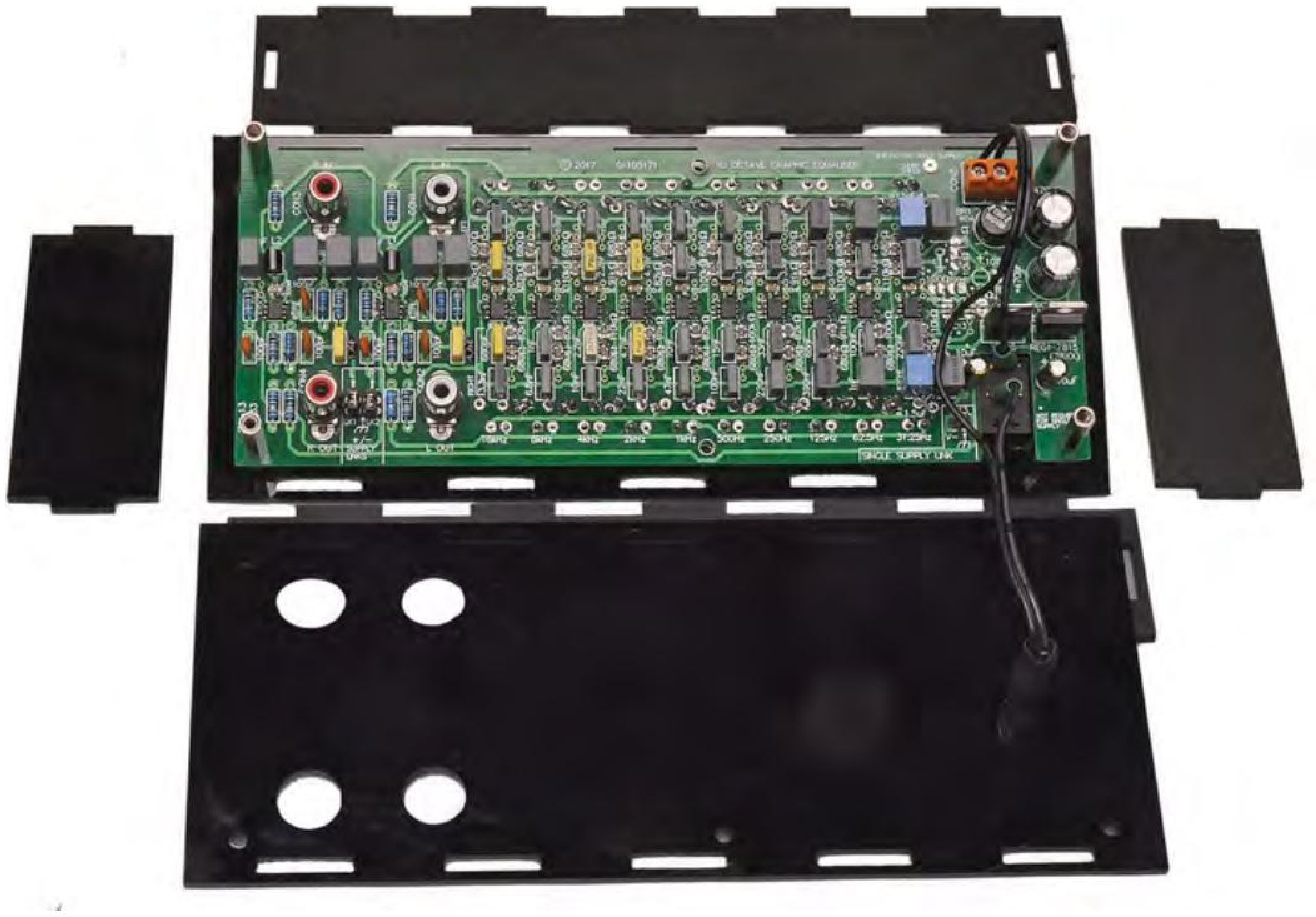
LED1 also needs to mount with the correct orientation (longer lead is the anode) and with the top of the lens 12mm above the PCB.

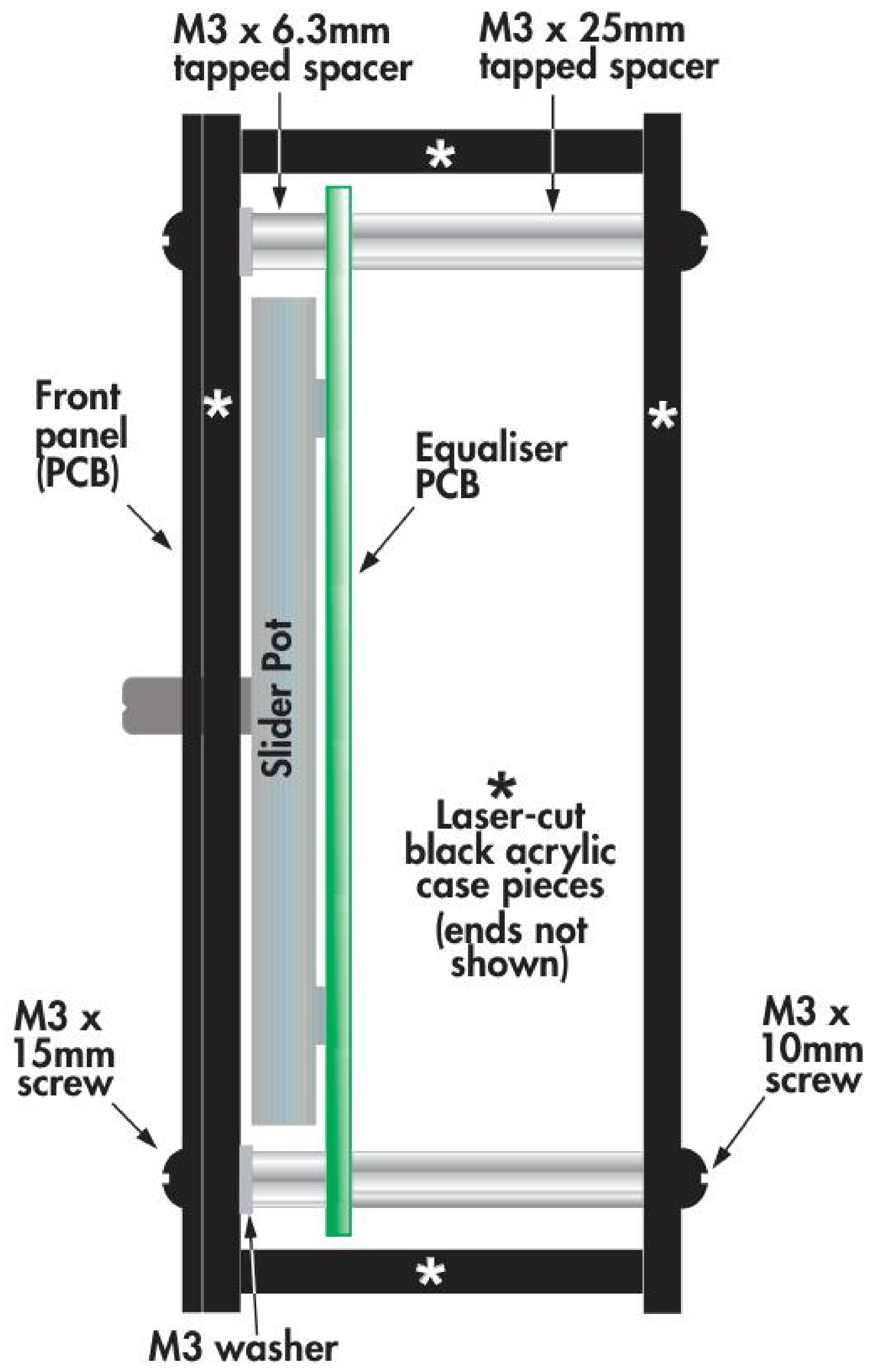
Initial testing

Power can now be applied to the equaliser circuit to test for voltage at the op amps. For the single 16VAC supply, connect the supply leads between an AC input (one of the outer terminals of CON5) and the centre 0V terminal.

If your supply is from an existing piece of equipment with a 30V centre-tapped transformer, connect the two AC voltages to each of the outer terminals of CON5 and the centre tap to the centre 0V terminal. The transformer must be capable of supplying the extra current drawn by the equaliser circuit (55mA typical, so allow for, say, 100mA).

Power up the circuit and the LED should light. Now measure the DC voltage between pin 4 and pin 8 of





The PCB is in position, with the slider-pot shafts poking through the front panel and the board held in place with threaded spacers. The diagram at right (Fig.10) shows how the PCB and case components fit together

one of the op amps. This should be close to 30V if you are using the AC supply and 15V (or less depending on whether you have a 12V regulator or if it is bridged out).

For the DC supply version, check that the voltage between pin 4 of any IC to pins 3 and pins 5 shows half the supply voltage. In other words, this voltage should be +7.5V or thereabouts if you have a 15V supply between pin 4 and pin 8.

Case installation

Fig.10 shows the assembly of the Acrylic case. Note that we show the mains transformer in the circuit for the centre-tapped 30V supply but a transformer will not fit in the acrylic case.

In addition, the power switch used in the case is not intended for switching mains voltages which could otherwise induce hum into the graphic equaliser circuitry. **The power switch is only intended for low-voltage switching.**

For the DC supply, the polarity needs to be correct and this depends on the wiring to the plug that connects to the socket. There will be no power supplied to the circuit if polarity is incorrect.

You need to have the positive connected to the outer terminal of CON5, so swap the two leads to the DC socket if the voltage is reversed. The wiring to the switch and socket are covered in heatshrink tubing.

The case is assembled as shown with the front panel PCB attached to the front of the case using M3 × 15mm screws secured with tapped 6.3mm-long M3 spacers. These are placed at the four corner-mounting positions on the PCB.

A washer is placed under each spacer first to increase clearance.

The two mounting holes in the middle of the PCB, top and bottom are secured to the front of the case with M3 × 10mm screws and M3 nuts.

The main equaliser PCB is then placed over the screws protruding through the 6.3mm-long spacers and with the slider adjustment shafts protruding through slots in the front panel and front PCB.

The PCB is secured using the M3 × 25mm spacers. The rear panel of the case is secured to these spacers using M3 × 10mm screws after the top and side pieces of the case are attached in place.

The holes in the rear of the case for the RCA sockets are made with large enough clearance so that RCA plugs can pass through the hole and on to the sockets.

So connect up your new equaliser for a new listening experience. Enjoy!

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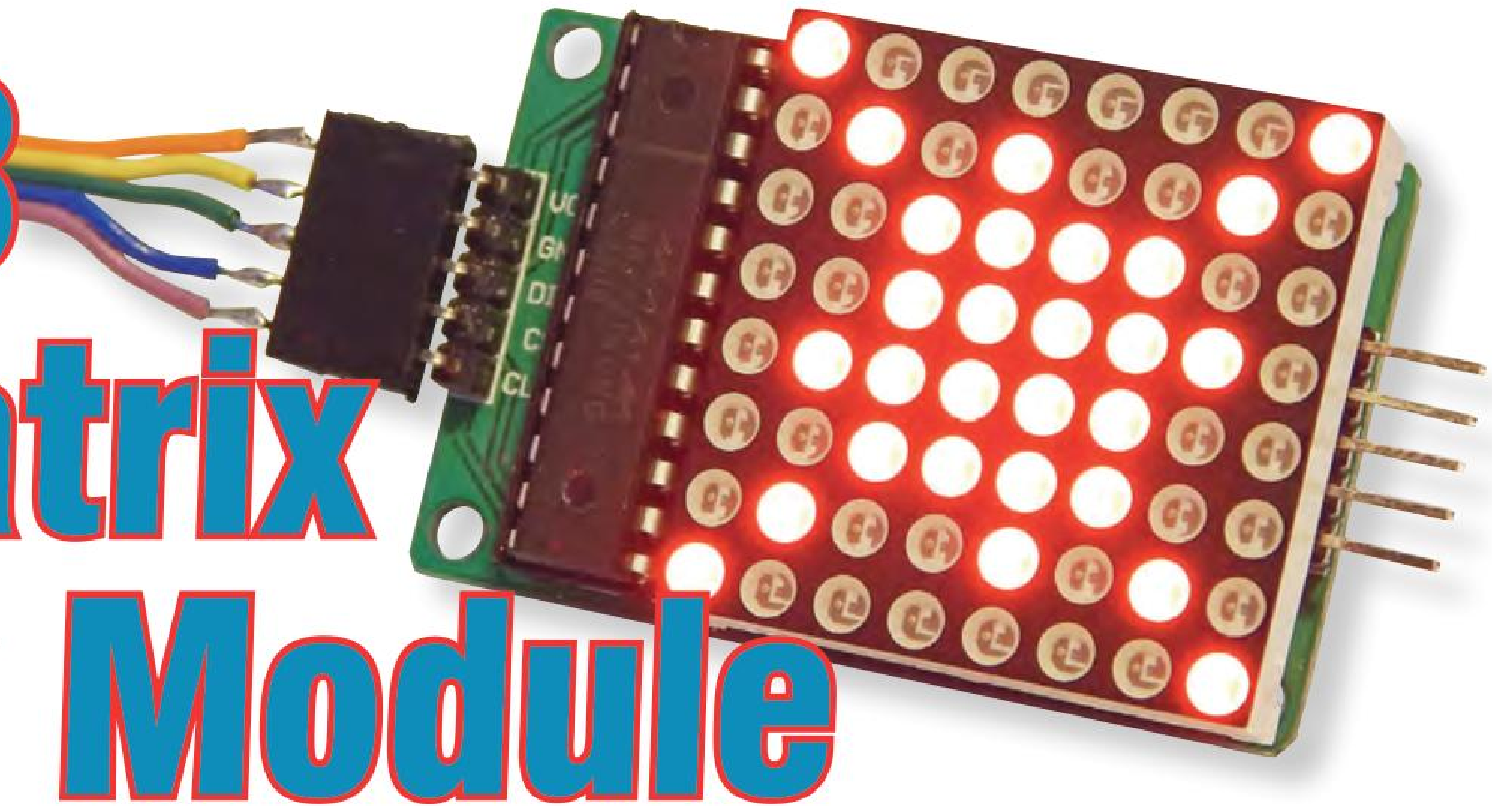
And finally, the case components are slotted together ready for the PCB/front panel assembly to be slipped into place and screws fitted to the four threaded spacers to complete assembly.

SPI 8x8 LED Matrix Display Module



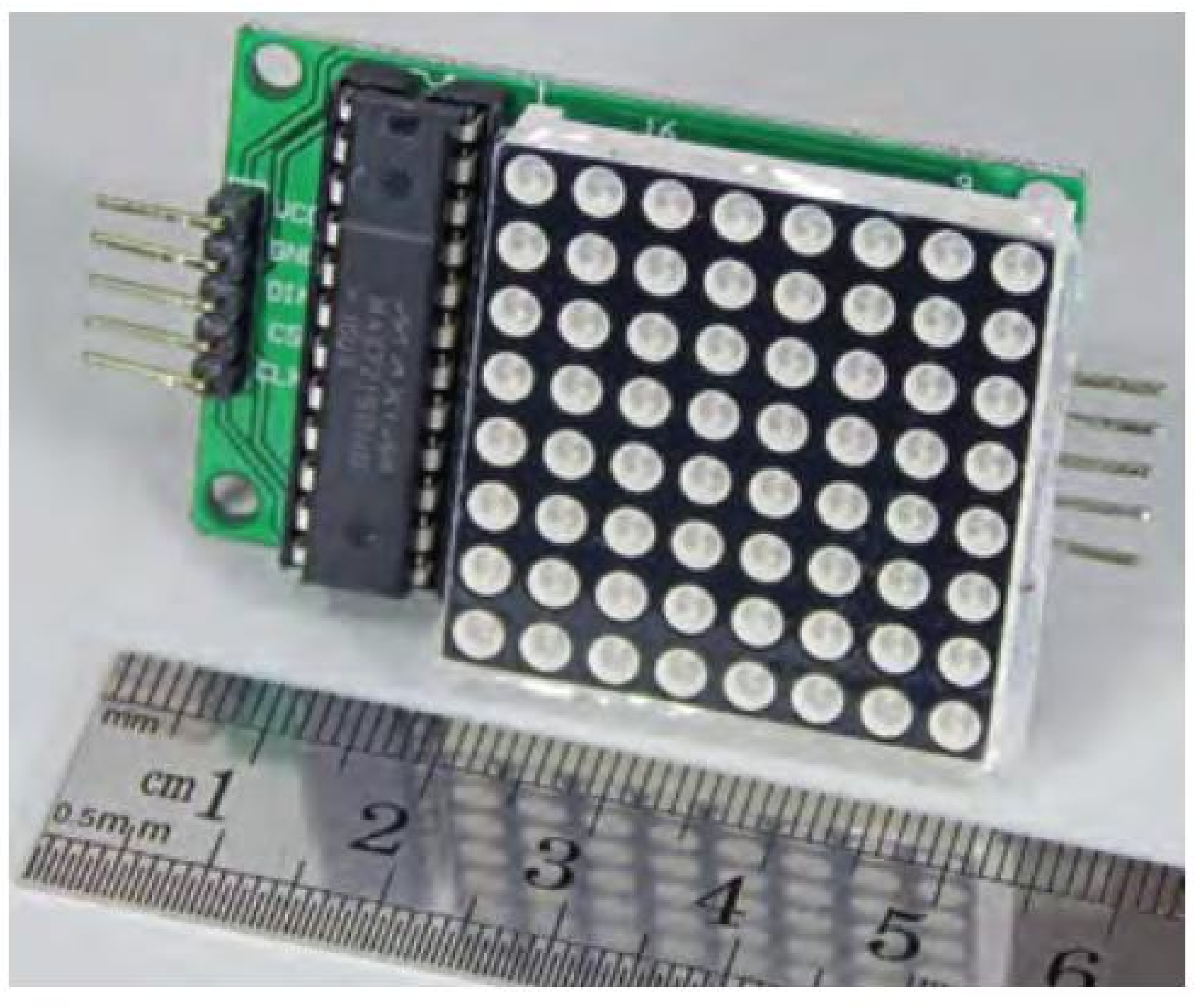
Using Cheap Asian Electronic Modules Part 7: by Jim Rowe

This low-cost module uses a Maxim MAX7219 serial LED display chip and comes complete with a plug-in 8x8 LED matrix display. However, the MAX7219 is equally capable of driving an 8-digit 7-segment LED display, and its SPI interface allows it to be driven by a microcontroller using only three wires, meaning both the module and the chip are surprisingly flexible.

When I first noticed this type of 8×8 LED matrix display module being offered on eBay and AliExpress, I must confess that I didn't get overly excited. Sure, they were very cheap – but what could you actually use an 8x8 LED matrix display for? All I could think of was displaying a few pretty patterns. Fun, perhaps, but not all that useful.

Despite this ho-hum first impression, I decided to order a couple of the modules just to see if they had any other uses. And when they arrived, I discovered that they did.

The data sheet for the MAX7219 controller chip is available from Maxim's website (**http://bit.ly/2I5Rz1Q**) and indicates that it has primarily been designed to drive an 8-digit 7-segment LED display. In fact, the ability to drive an 8x8 LED matrix is in many ways just a bonus feature!



This very cheap module includes the MAX7219 IC and a plug-in 8×8 LED matrix display.

Inside the MAX7219

To understand the dual personality of the MAX7219, take a quick look at the block diagram in Fig.1. As you can see, there's more inside this modest-looking 24-pin DIP device than you might have expected.

Down at the bottom, you can see the 16-bit shift register where data and instructions are shifted into the chip from almost any micro, via a standard SPI (Serial Peripheral Interface) bus. Above the eight least-significant bits (D0-D7) is an eight-byte dual-port SRAM, where the display data is stored.

Four more bits, D8-D11, are decoded to determine whether the data in the lower eight bits of the shift register is to be loaded into one of the addresses in the display SRAM (either with or without further decoding), or into one of the control registers to set the chip's operating modes.

Five registers control shutdown, the mode, intensity, scan limit and display test.

The shutdown register blanks the display when power is first applied or at a later time, to reduce the power consumption. It can also be used to flash the display on and off, for 'alarm' situations. During normal operation, data bit D0 of this register is set to one.

The mode register is used to control whether the data in the SRAM registers for each digit is to be decoded (according to 'CODE B') or used as-is. The interesting point here is that the mode register can be set for decoding all eight digits, none of them or virtually any combination in between.

So for driving an 8×8 LED matrix, for example, you wouldn't use the decoding features, while for driving an 8-digit 7-segment display you'd program it to decode all eight registers.

But you could also use it to drive a 6-digit 7-segment display by decoding just those six digits, with the remaining two digit positions either unused or used without decoding to drive other indicator LEDs. So it's quite flexible.

The intensity register provides programmable digital control over the brightness of the LEDs. As you can see from Fig.1, the chip has a segment current reference circuit (at upper left), controlled by the current fed in via the I_{SET} pin (pin 18).

The peak current sourced from the chip's segment driver outputs (upper right) is nominally 100 times the current entering the I_{SET} pin, which is normally connected to the +5V supply rail via a resistor of 9.53kΩ or more. The module shown in the pictures uses a 10kΩ resistor.

At the same time, the value stored in bits D0-D3 of the intensity control register determines the duty cycle of the chip's internal pulse-width modulator, and hence the display brightness. The duty cycle is a 4-bit value, meaning that there are 16 different programmable duty cycle/brightness levels, from 1/32 (3%) to 31/32 (97%).

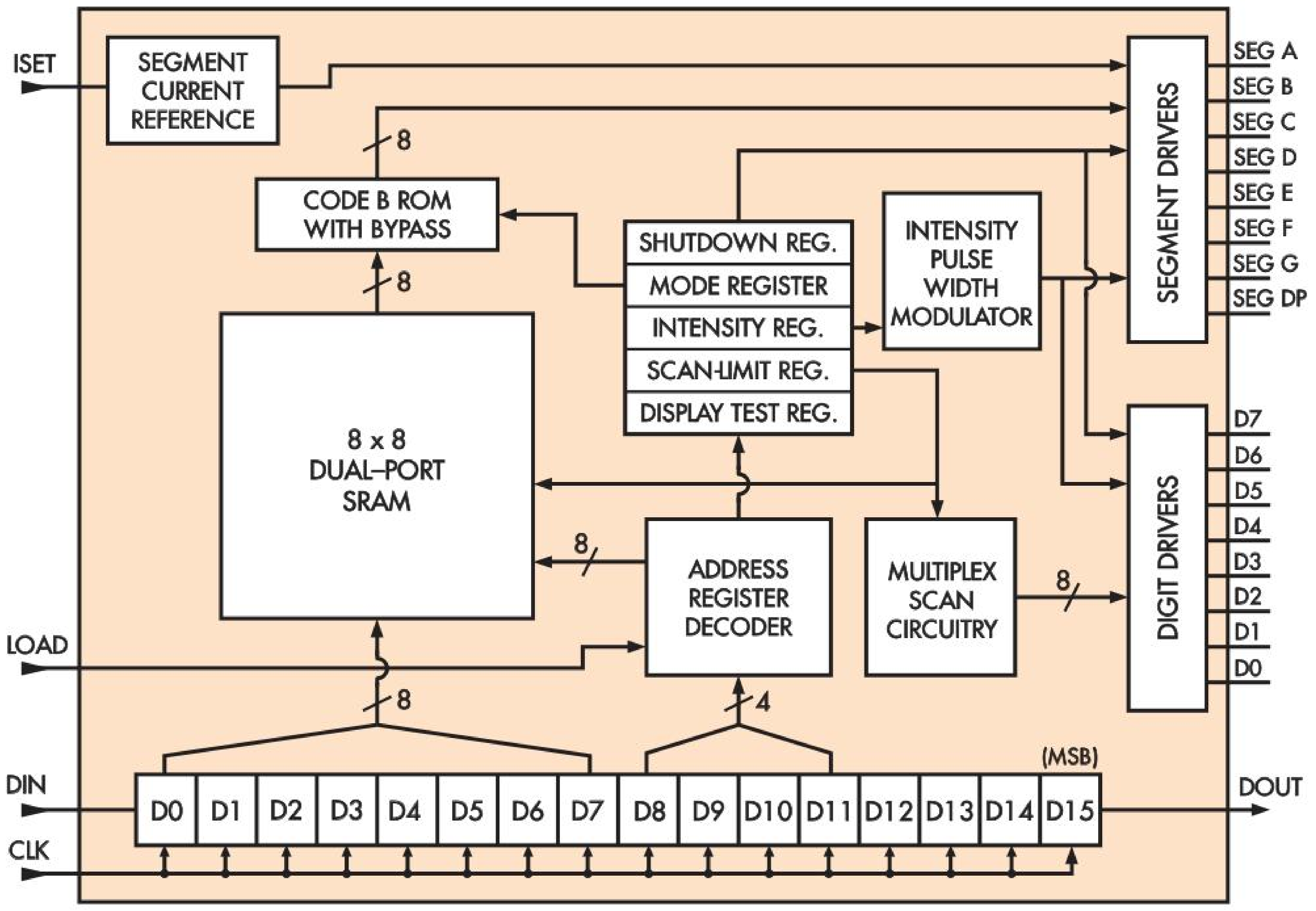


Fig.1: internal block diagram of the MAX7219 IC. The 8-byte dual-port SRAM is used to store the current LED state, while the decoder block simplifies the software required to drive a 7-segment display. The segment drivers supply a fixed current determined by the current flow out of the I_{SET} pin, and intensity is modulated by PWM applied by those same segment drivers.

Then there's the scan limit control register, which is basically used to determine how many digits are scanned by the display multiplexing circuitry. This allows the chip to be programmed for any number of display digits between one and eight.

Do note that Maxim warns in the datasheet that if three or fewer digits are selected, the resistor connected to the chip's I_{SET} pin should be increased in value to reduce the power dissipation in the digit drivers.

Finally, there's the display test control register, which can be used to switch between normal operation and the test mode, where all segments are lit in order to test the display itself.

To help you put all of these functions of the MAX7219 into perspective, Fig.2 summarises the decoding of register address bits D8-D11, while Fig.3 shows the significance of data bits D0-D7 when segment decoding (ie, 'CODE B') is enabled (A) or decoding is disabled (B).

Driving the 8x8 LED matrix

So that's a quick run-down on the MAX7219 device and its internal working. Fig.4 shows the full circuit for the module as it arrives, and it has everything needed to drive the 8x8 LED matrix directly from a micro like an Arduino or a Micromite.

There's very little to the module apart from the MAX7219 (IC1), the 8x8 LED matrix and the two 8-pin connectors (CON2 and CON3) used to join them together.

There are two 5-pin SIL connectors; one used for the supply and serial bus inputs (CON1) and the other for the matching outputs (CON4) used for daisy-chaining further modules, plus the 10kΩ resistor connected to IC1's I_{SET} pin and a pair of bypass capacitors on the 5V supply line, one 100nF and one 10µF electrolytic.

Programming it to produce interesting patterns turns out to be fairly straightforward, as we'll see shortly. But before we do so, you'll recall that I mentioned earlier that the MAX7219 was originally intended for driving 7-segment LED displays of up to eight digits.

Driving 8-digit 7-segment displays

This configuration is shown in Fig.5, with a pair of 4×7-segment displays wired to CON2 and CON3 of the module instead of an 8×8 LED matrix. Note that for space reasons, we haven't shown the MAX7219 chip or the rest of the module circuitry to the left of CON2 and CON3 in Fig.5, but these are all exactly the same as in Fig.4.

In fact, the only changes needed to drive a pair of 4×7-segment displays instead of an 8×8 LED matrix with the MAX7219 module are in software rather than hardware.

Specifically, it's just a matter of enabling decoding for all eight digits, instead of disabling it, as required for driving the 8x8 LED matrix.

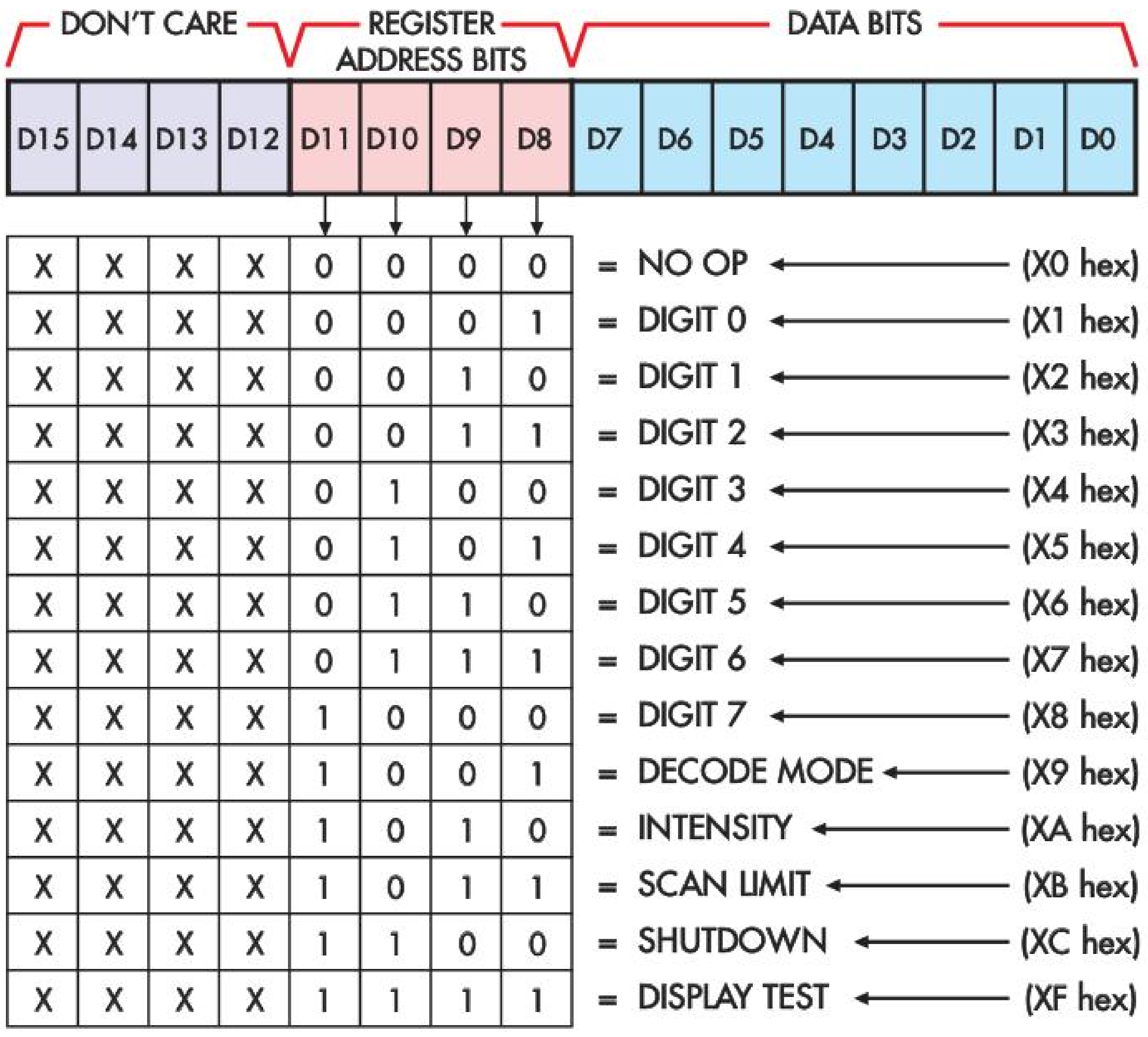
This leads us to hooking the MAX7219 module up to popular micros and programming it to display what you want. In fact, not only is it possible to drive an 8-digit display using a MAX7219, pre-built modules are available on eBay and AliExpress. These incorporate a PCB with an SMD MAX7219 on the back and two 4-digit 7-segment displays plugged into header sockets on the front. Like the 8x8 matrix displays, they have 6-pin connectors at each end to wire up to your micro and also allow daisy chaining.

Driving them from an Arduino

As shown in Fig.6, it's quite easy to connect these modules up to almost any Arduino or Arduino clone, by taking advantage of the fact that most of the connections needed for interfacing to an SPI peripheral are made available on the 6-pin ICSP header fitted to most Arduino variants.

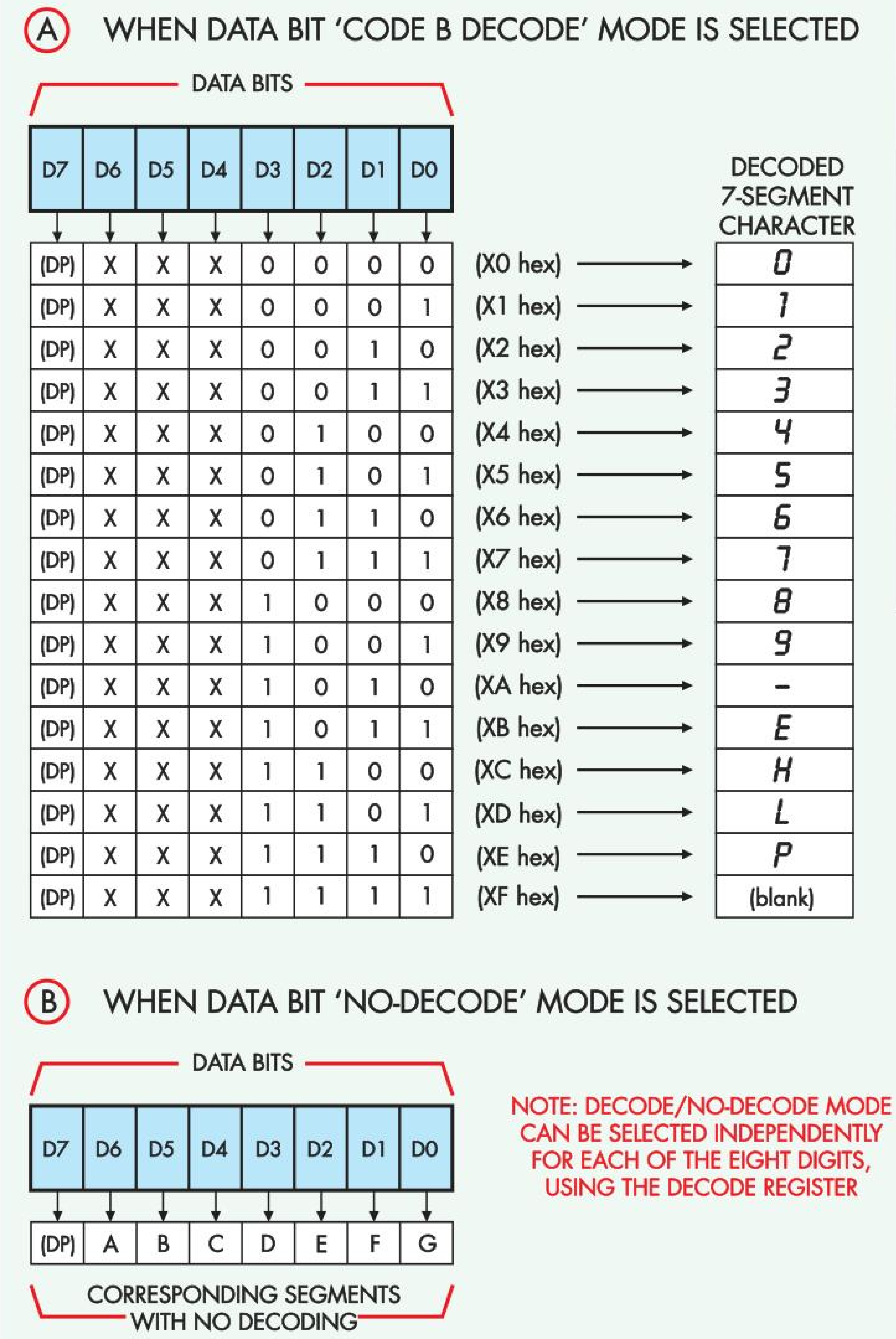
The connections to the ICSP header are fairly consistent over just about all Arduino variants, including the Uno, Leonardo and Nano, the Freetronics Eleven and LeoStick, and the Duinotech Classic or Nano.

In fact the only connection that's not available via the ICSP header is the one for SS/CS/LOAD, which needs

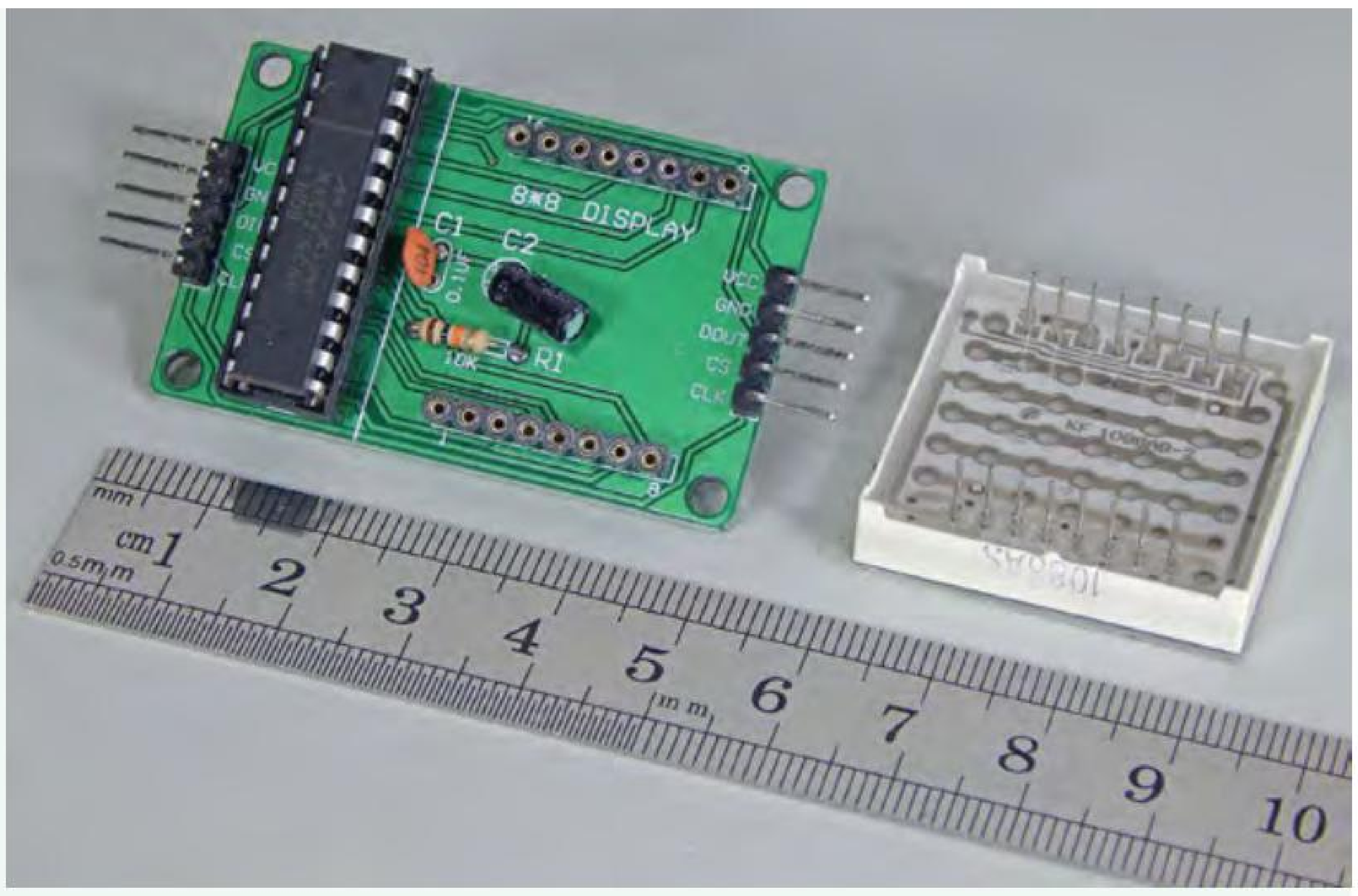

DON'T CARE
REGISTER ADDRESS BITS
DATA BITS
D15 D14 D13 D12 D11 D10 D9 D8 D7 D6 D5 D4 D3 D2 D1 D0

D15	D14	D13	D12	D11	D10	D9	D8		
X	X	X	X	0	0	0	0	= NO OP	(X0 hex)
X	X	X	X	0	0	0	1	= DIGIT 0	(X1 hex)
X	X	X	X	0	0	1	0	= DIGIT 1	(X2 hex)
X	X	X	X	0	0	1	1	= DIGIT 2	(X3 hex)
X	X	X	X	0	1	0	0	= DIGIT 3	(X4 hex)
X	X	X	X	0	1	0	1	= DIGIT 4	(X5 hex)
X	X	X	X	0	1	1	0	= DIGIT 5	(X6 hex)
X	X	X	X	0	1	1	1	= DIGIT 6	(X7 hex)
X	X	X	X	1	0	0	0	= DIGIT 7	(X8 hex)
X	X	X	X	1	0	0	1	= DECODE MODE	(X9 hex)
X	X	X	X	1	0	1	0	= INTENSITY	(XA hex)
X	X	X	X	1	0	1	1	= SCAN LIMIT	(XB hex)
X	X	X	X	1	1	0	0	= SHUTDOWN	(XC hex)
X	X	X	X	1	1	1	1	= DISPLAY TEST	(XF hex)

Fig.2: data is sent to the MAX7219 over a serial bus, 16 bits at a time. This table shows how bits 8-11 determine which register is written to, while bits 0-7 contain the new data for that register. With bits 8-11 set to a value between 1 and 8, one of the entries in the dual-port SRAM is updated while values of between 9 and 12 or 15 are used to write to one of the five control registers.


A
WHEN DATA BIT 'CODE B DECODE' MODE IS SELECTED
DATA BITS
B
WHEN DATA BIT 'NO-DECODE' MODE IS SELECTED
DATA BITS
D7 D6 D5 D4 D3 D2 D1 D0
(DP) A B C D E F G
CORRESPONDING SEGMENTS WITH NO DECODING
NOTE: DECODE/NO-DECODE MODE CAN BE SELECTED INDEPENDENTLY FOR EACH OF THE EIGHT DIGITS, USING THE DECODE REGISTER

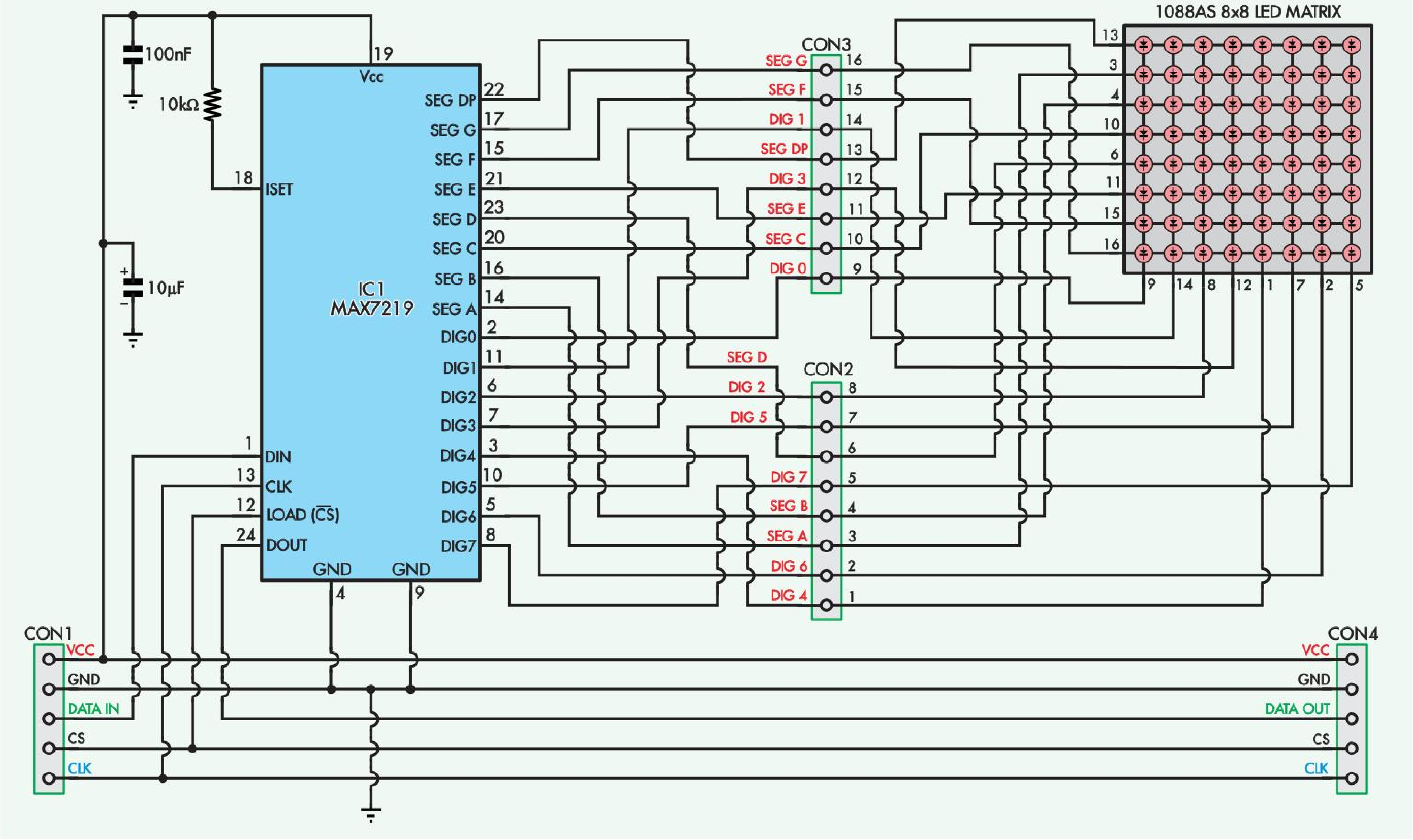
D7	D6	D5	D4	D3	D2	D1	D0		DECODED 7-SEGMENT CHARACTER
(DP)	X	X	X	0	0	0	0	(X0 hex)	0
(DP)	X	X	X	0	0	0	1	(X1 hex)	1
(DP)	X	X	X	0	0	1	0	(X2 hex)	2
(DP)	X	X	X	0	0	1	1	(X3 hex)	3
(DP)	X	X	X	0	1	0	0	(X4 hex)	4
(DP)	X	X	X	0	1	0	1	(X5 hex)	5
(DP)	X	X	X	0	1	1	0	(X6 hex)	6
(DP)	X	X	X	0	1	1	1	(X7 hex)	7
(DP)	X	X	X	1	0	0	0	(X8 hex)	8
(DP)	X	X	X	1	0	0	1	(X9 hex)	9
(DP)	X	X	X	1	0	1	0	(XA hex)	-
(DP)	X	X	X	1	0	1	1	(XB hex)	E
(DP)	X	X	X	1	1	0	0	(XC hex)	H
(DP)	X	X	X	1	1	0	1	(XD hex)	L
(DP)	X	X	X	1	1	1	0	(XE hex)	P
(DP)	X	X	X	1	1	1	1	(XF hex)	(blank)



Above is the layout of the module without the 7-segment display and below in Fig.4 is the matching circuit diagram.

Fig.3 (left): when 'Code B' decoding is active for a segment, the lower four bits of the value for that segment form a look-up table for one of 16 possible 7-segment display configurations, as shown at right. The top bit determines whether the decimal point is lit. Compare this to (B) at bottom, where decoding is not active and the eight bits in SRAM control the segment drivers directly.

Fig.4 (below): the circuit of a typical pre-built 8×8 LED matrix module with MAX7219 driver. A photo of this type of module is shown above. There's virtually nothing to it, just the LED matrix display module, the MAX7219 IC and some connectors to join them together and to provide connections to the microcontroller and optionally, more daisy-chained LED displays.


100nF
10kΩ
10µF
19
Vcc
18
ISET
IC1
MAX7219
SEG DP 22
SEG G 17
SEG F 15
SEG E 21
SEG D 23
SEG C 20
SEG B 16
SEG A 14
DIG0 2
DIG1 11
DIG2 6
DIG3 7
DIG4 3
DIG5 10
DIG6 5
DIG7 8
1 DIN
13 CLK
12 LOAD (CS)
24 DOUT
GND 4
GND 9
CON3
SEG G 16
SEG F 15
DIG 1 14
SEG DP 13
DIG 3 12
SEG E 11
SEG C 10
DIG 0 9
CON2
SEG D
DIG 2 8
DIG 5 7
6
DIG 7 5
SEG B 4
SEG A 3
DIG 6 2
DIG 4 1
1088AS 8x8 LED MATRIX
13 3 4 10 6 11 15 16
9 14 8 12 1 7 2 5
CON1
VCC
GND
DATA IN
CS
CLK
CON4
VCC
GND
DATA OUT
CS
CLK

to be connected to the IO10/SS pin of an Arduino Uno, Freetronics Eleven or Duinotech Classic, as shown in Fig.6.

With other variants, you should be able to find the corresponding pin without too much trouble – and even if you can't find it, the pin reference can be changed in your software sketch to match the pin which you decide to use.

Driving them from a Micromite

It's also quite easy to drive these modules from a Micromite, using the connections shown in Fig.7. By connecting the MOSI, SCK and SS/

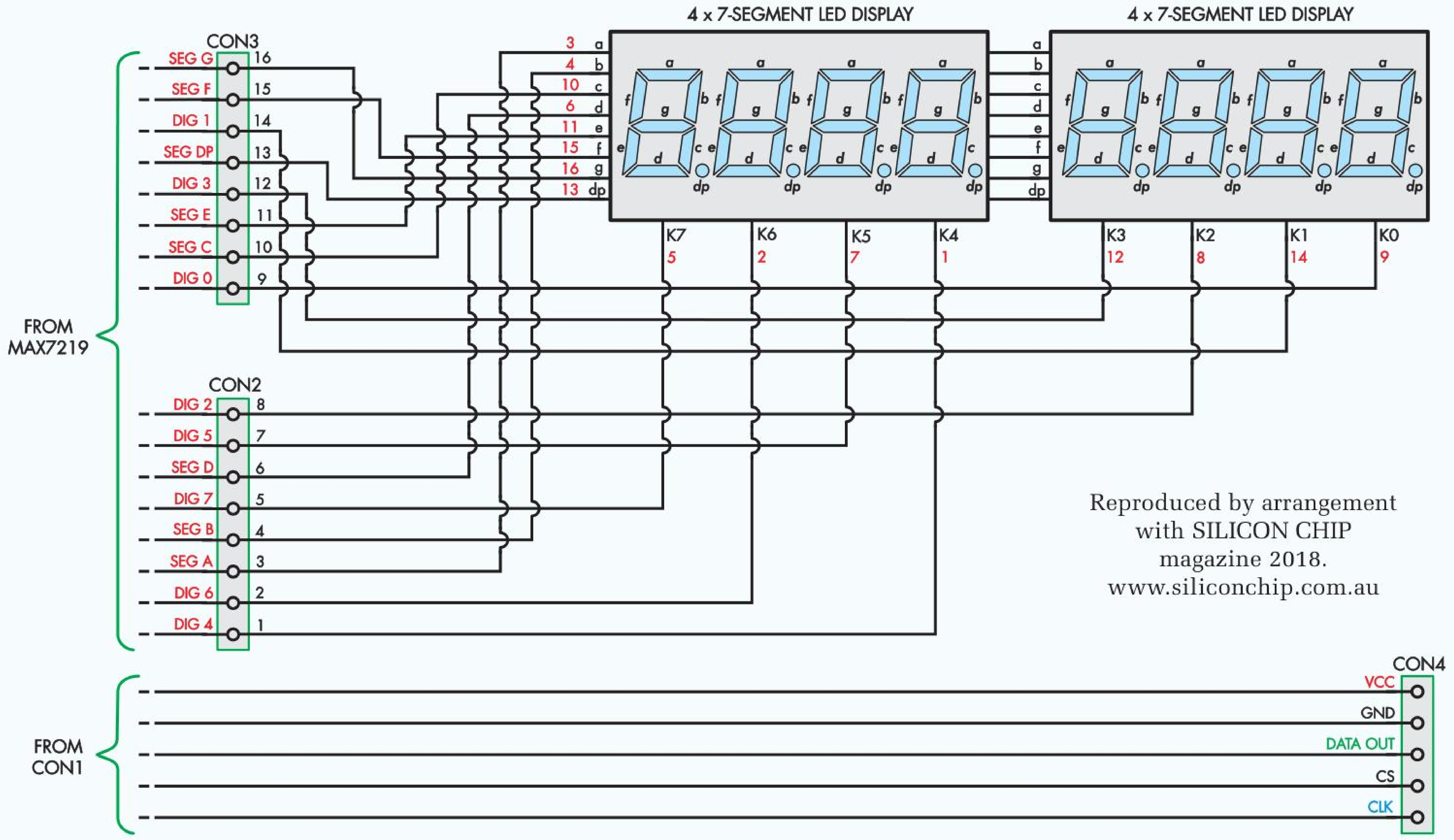

4 x 7-SEGMENT LED DISPLAY
4 x 7-SEGMENT LED DISPLAY
CON3
SEG G 16
SEG F 15
DIG 1 14
SEG DP 13
DIG 3 12
SEG E 11
SEG C 10
DIG 0 9
FROM MAX7219
CON2
DIG 2 8
DIG 5 7
SEG D 6
DIG 7 5
SEG B 4
SEG A 3
DIG 6 2
DIG 4 1
3 a
4 b
10 c
6 d
11 e
15 f
16 g
13 dp
K7 5
K6 2
K5 7
K4 1
K3 12
K2 8
K1 14
K0 9
CON4
VCC
GND
DATA OUT
CS
CLK
FROM CON1

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Fig.5: the circuit of a typical pre-built 8-digit 7-segment common-cathode LED display using a MAX7219. Pre-built modules for this configuration are also available. We haven't shown the IC itself, as its configuration is identical to that of Fig.4 – all that's changed is that in place of the 8x8 LED matrix are two 4-digit 7-segment displays with the anodes wired in parallel.

LOAD lines to Micromite pins 3, 25 and 22 as shown, MMBasic's built-in SPI protocol commands will have no trouble in communicating with the module.

So that's the basic story regarding the hardware side of the MAX7219-based module which can drive either an 8x8 LED matrix array or eight 7-segment LED displays.

Before we finish, a few words are in order regarding the software side, ie, how to write programs to get the module to display what you want.

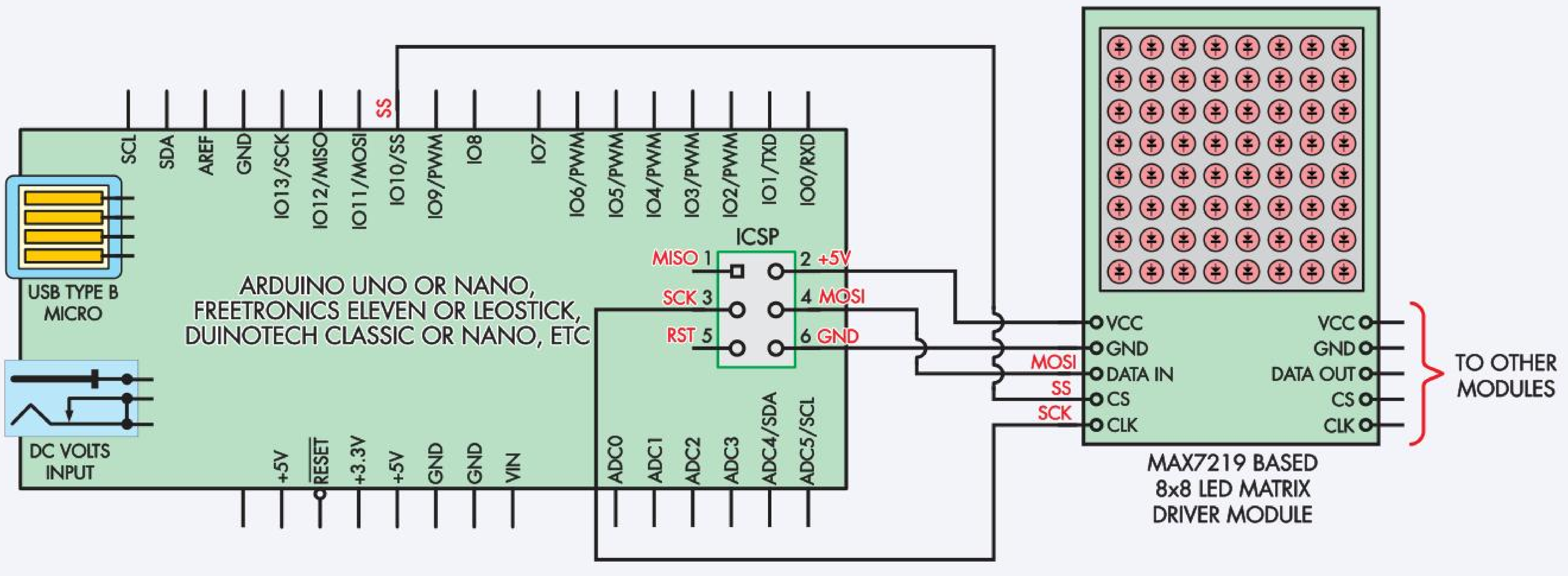
Writing the software

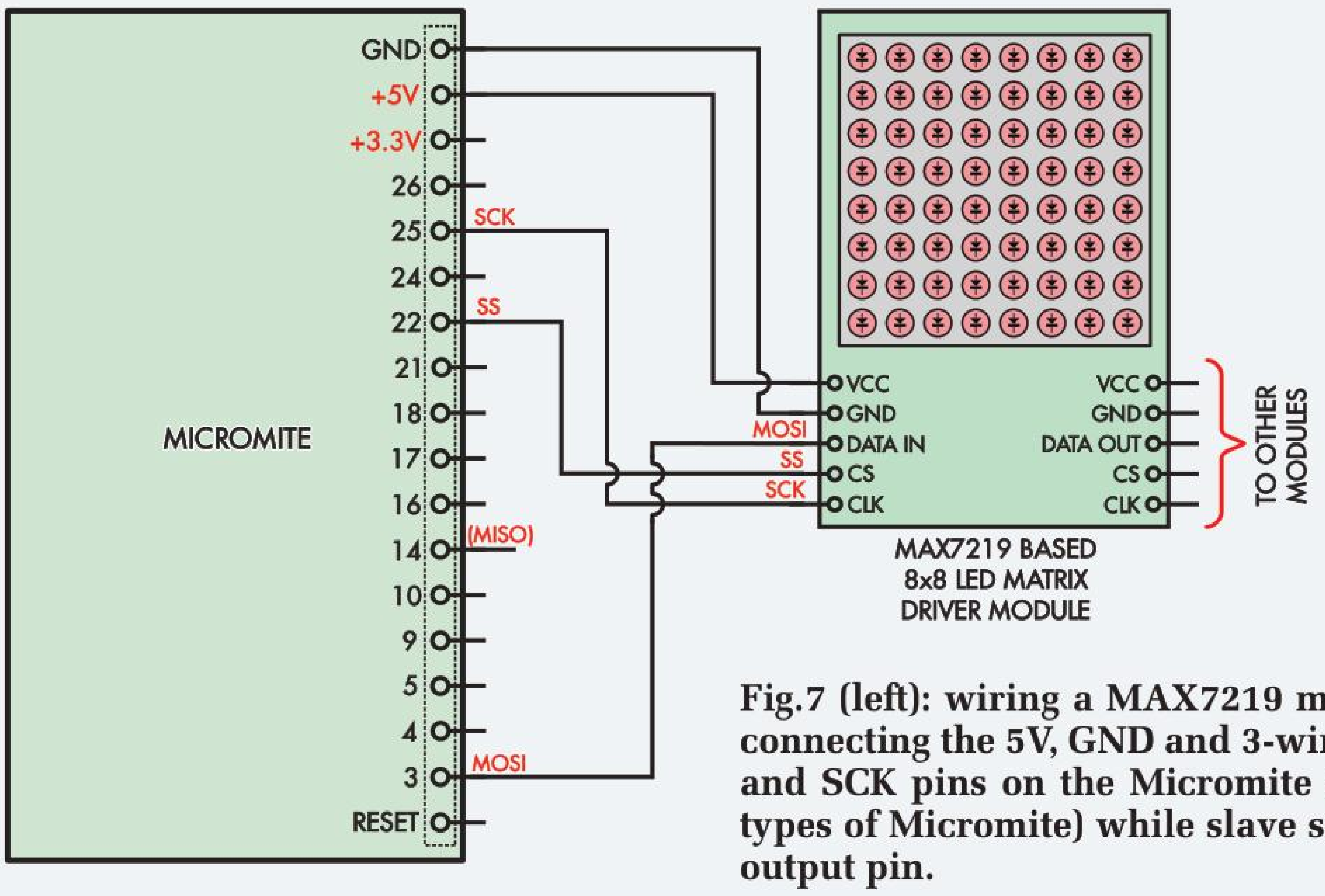
The basic idea here is that when your program starts up, it needs to carry out a number of set-up tasks:

- Declare the micro's pins that are going to be used by the SPI interface and set them to their idle state (normally high).
- Start up the SPI interface, with its settings configured for a clock rate of say 5MHz, the data to be sent MSB (most-significant bit) first and using clock/data timing mode 0. If possible, it should also be set for the data to be exchanged in 16-bit words rather than bytes.
- Send the initialisation commands to the MAX7219 to set up its five control registers: shutdown, decode mode, intensity, scan limit and display test.

After these tasks have been done, you should be able to send out the actual display data for each of the 8-digit display addresses in the MAX7219's SRAM. And if the display is to be a dynamic one, you

Fig.6: connecting either type of MAX7219-based module to an Arduino is easy. Simply wire up the SPI pins and power supply to the ICSP header on the Arduino and the CS pin to a free GPIO – ideally IO10, which is the hardware slave select (SS) pin.


SS
SCL
SDA
AREF
GND
IO13/SCK
IO12/MISO
IO11/MOSI
IO10/SS
IO9/PWM
IO8
IO7
IO6/PWM
IO5/PWM
IO4/PWM
IO3/PWM
IO2/PWM
IO1/TXD
IO0/RXD
USB TYPE B MICRO
ARDUINO UNO OR NANO, FREETRONICS ELEVEN OR LEOSTICK, DUINOTECH CLASSIC OR NANO, ETC
ICSP
MISO 1
2 +5V
SCK 3
4 MOSI
RST 5
6 GND
DC VOLTS INPUT
+5V
RESET
+3.3V
+5V
GND
GND
VIN
ADC0
ADC1
ADC2
ADC3
ADC4/SDA
ADC5/SCL
MOSI
SS
SCK
VCC
GND
DATA IN
CS
CLK
VCC
GND
DATA OUT
CS
CLK
TO OTHER MODULES
MAX7219 BASED 8x8 LED MATRIX DRIVER MODULE



Directly below – you can see the underside of the module is sparse, only having the markings for the connections to and from the module.

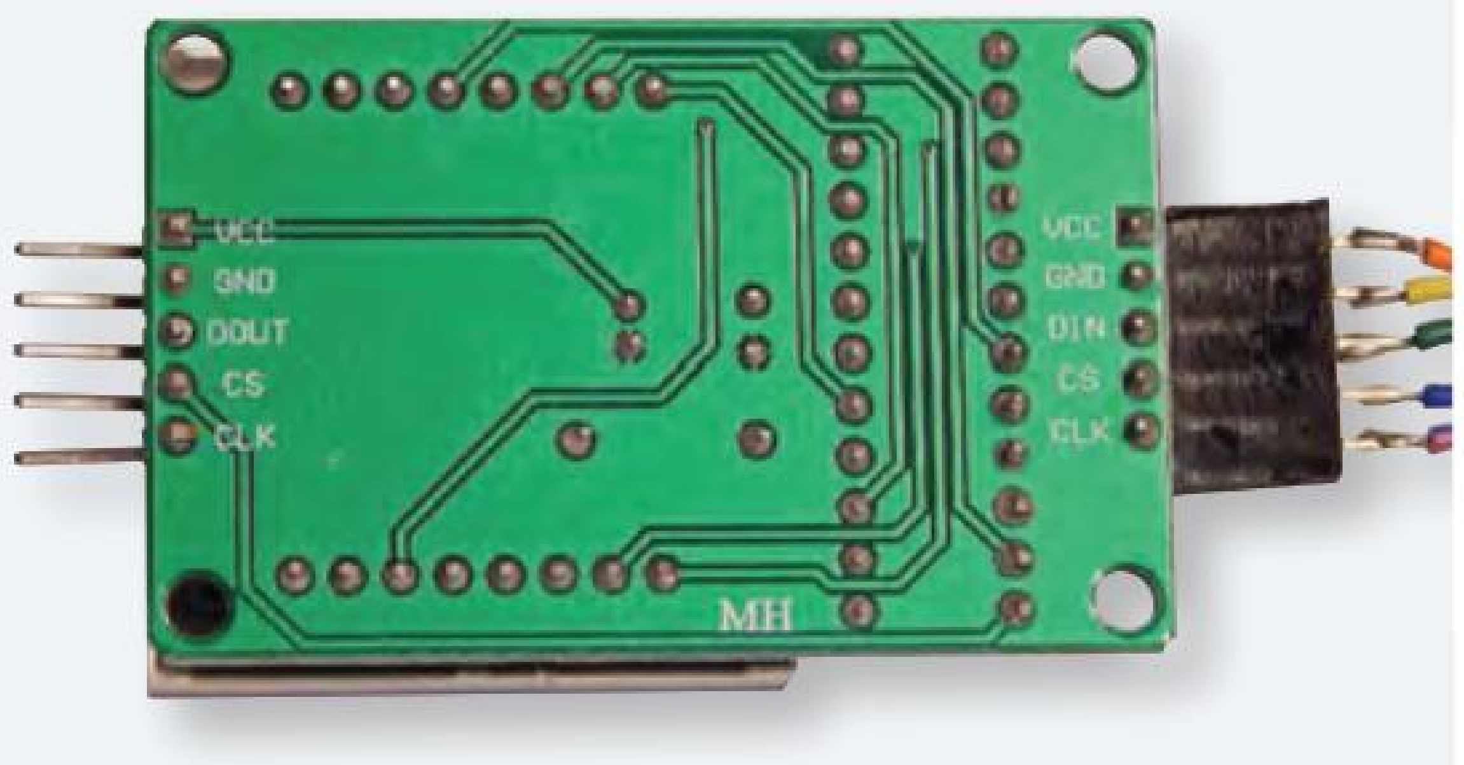


Fig.7 (left): wiring a MAX7219 module to a Micromite is simply a matter of connecting the 5V, GND and 3-wire SPI bus between the two units. The MOSI and SCK pins on the Micromite are fixed (and may vary between different types of Micromite) while slave select (SS) can go to pretty much any digital output pin.

can send out revised data at the appropriate times.

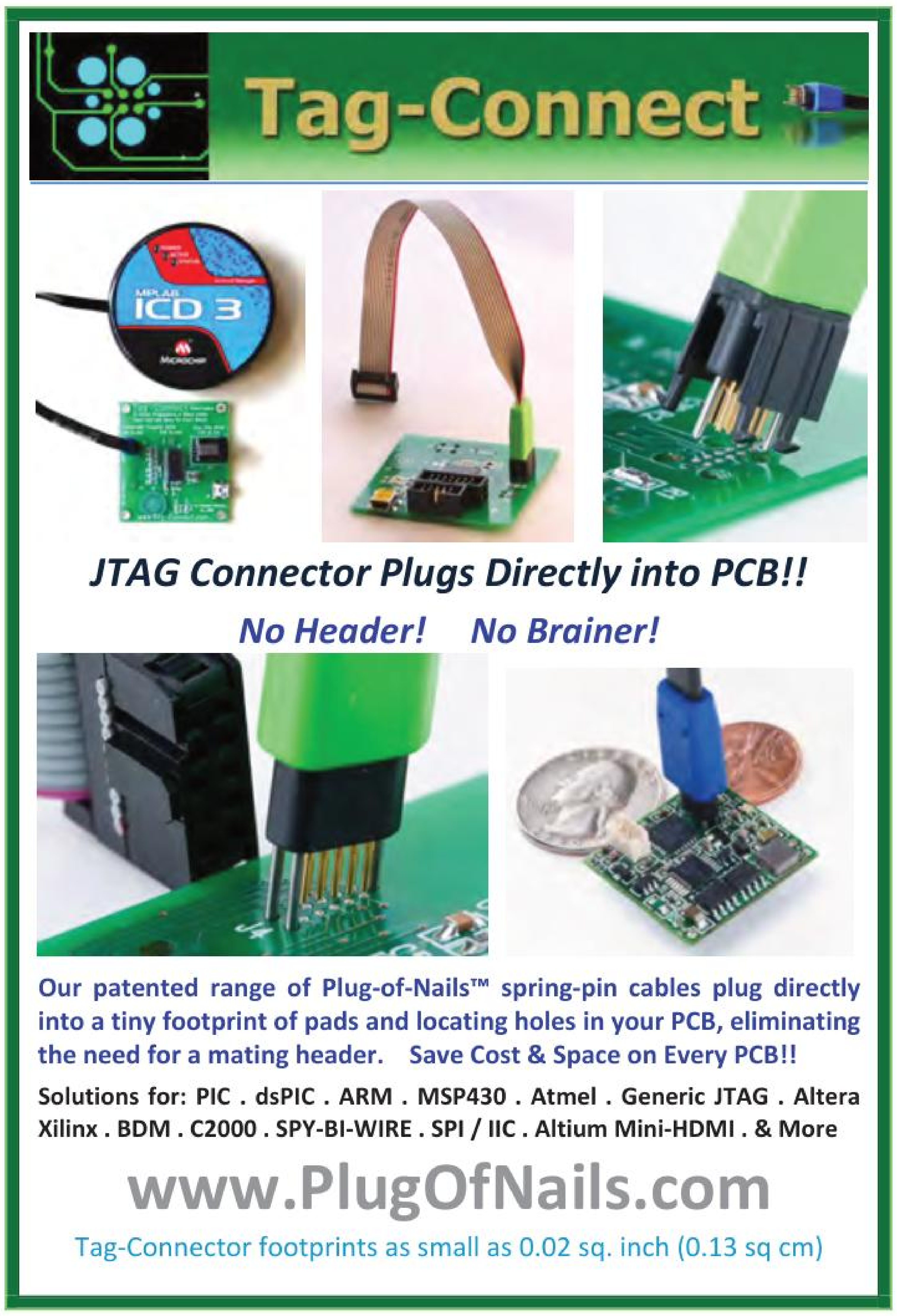
To help you understand what's involved in writing your own programs for the module, I have written a couple of simple example programs which repeatedly display an expanding star pattern on the 8x8 LED matrix array (you can see the fully expanded star on the lead photo).

One of these programs is written for Arduino and I have called it: **sketch2_for_Testing_MAX7219.ino**. The other program is written for the Micromite, and is called **MAX7219 LED array Star.bas** Both of these programs are available for download from the *EPE* website.

Both programs simply blank the display for a second or so, then cause a small square pattern to appear first in the centre of the array and then expand out fairly quickly to form a star, with its tips at the four corners of the array. The expanded star remains visible for about three seconds before the array is blanked again and the sequence repeats.

It's all quite simple, but either program should give you a reasonably clear guide regarding how to use the MAX7219 display driver module in your own projects.

I've tried to provide a lot of explanatory comments in both programs, to help in this regard.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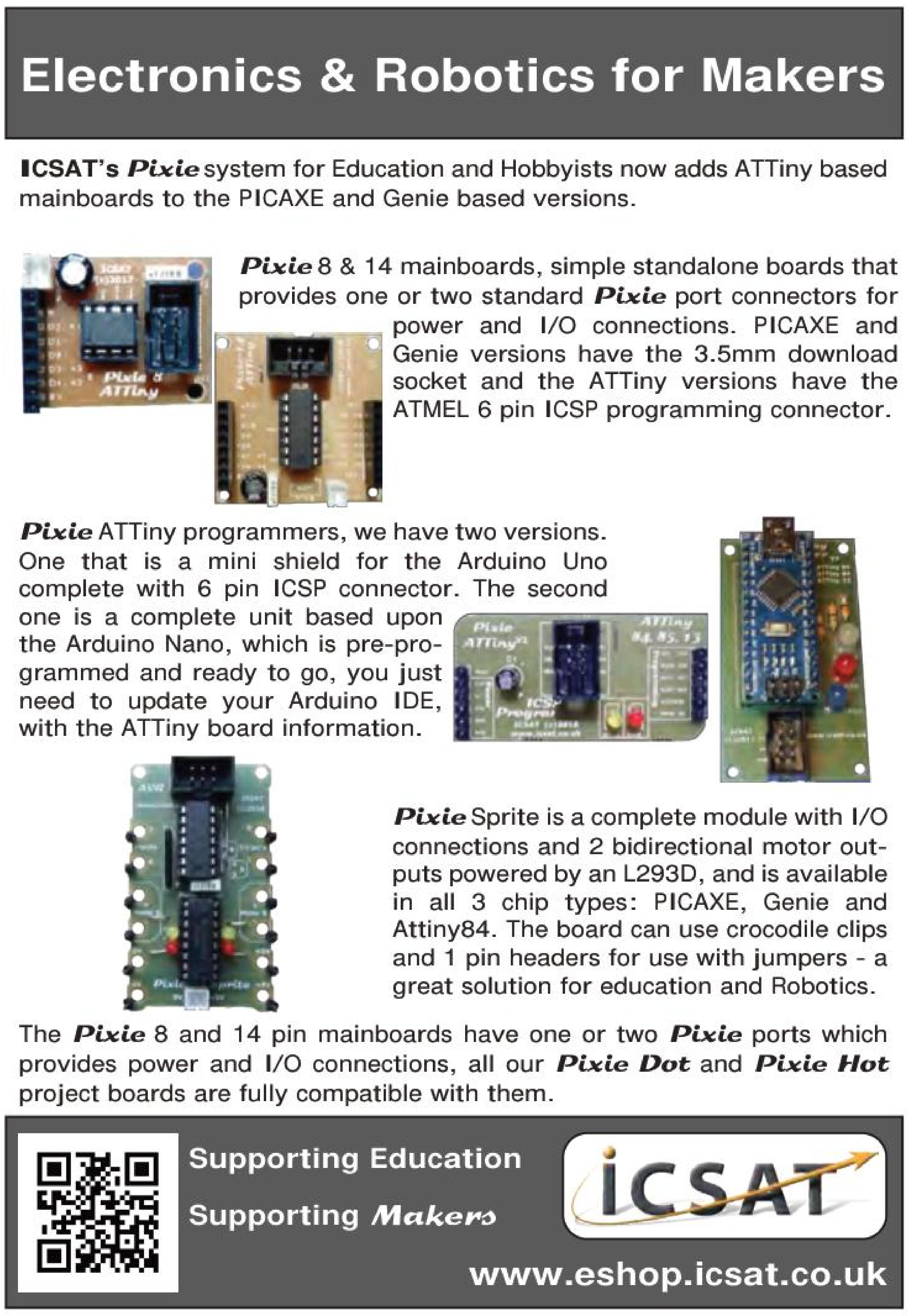
Electronics & Robotics for Makers

ICSAT's *Pixie* system for Education and Hobbyists now adds ATTiny based mainboards to the PICAXE and Genie based versions.

Pixie 8 & 14 mainboards, simple standalone boards that provides one or two standard *Pixie* port connectors for power and I/O connections. PICAXE and Genie versions have the 3.5mm download socket and the ATTiny versions have the ATMEL 6 pin ICSP programming connector.

Pixie ATTiny programmers, we have two versions. One that is a mini shield for the Arduino Uno complete with 6 pin ICSP connector. The second one is a complete unit based upon the Arduino Nano, which is pre-programmed and ready to go, you just need to update your Arduino IDE, with the ATTiny board information.

Pixie Sprite is a complete module with I/O connections and 2 bidirectional motor outputs powered by an L293D, and is available in all 3 chip types: PICAXE, Genie and Attiny84. The board can use crocodile clips and 1 pin headers for use with jumpers - a great solution for education and Robotics.

The *Pixie* 8 and 14 pin mainboards have one or two *Pixie* ports which provides power and I/O connections, all our *Pixie Dot* and *Pixie Hot* project boards are fully compatible with them.

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EPE product review

by Julian Edgar

Lascar PanelPilot voltmeter

Digital panel meters have been around forever, but here is a new and exciting take on the product. Just released by UK company Lascar is the SGD 21-B PanelPilot voltmeter; a new programmable meter with a new display technology.

So what makes this meter different?

First, the display uses a dot matrix e-paper design, allowing it to be read in any lighting condition – from full sunlight to very dim indeed. (However, there is no backlight, so it cannot be viewed in complete darkness.) Also, the display is visible from a wide range of viewing angles – far wider than a conventional LCD. Use of the e-paper design allows the meter to be powered by a low current supply (just 5mA). That supply can be anywhere in the 4.0-9.0V range – ideal for battery or USB-powered equipment.

Second, the meter is software programmable. Connect the meter to a PC via the USB port, and then, using the free Panel Pilot B software (download from the Lascar site), the meter can be configured in a variety of ways. We'll look at these in more detail in a moment, but the configurability includes not only the type of display (eg, a bar graph and a numerical display, or a numerical display that includes maximum and minimum) but also two alarms, scaling, the number of displayed decimal places and the function of a digital input pin.

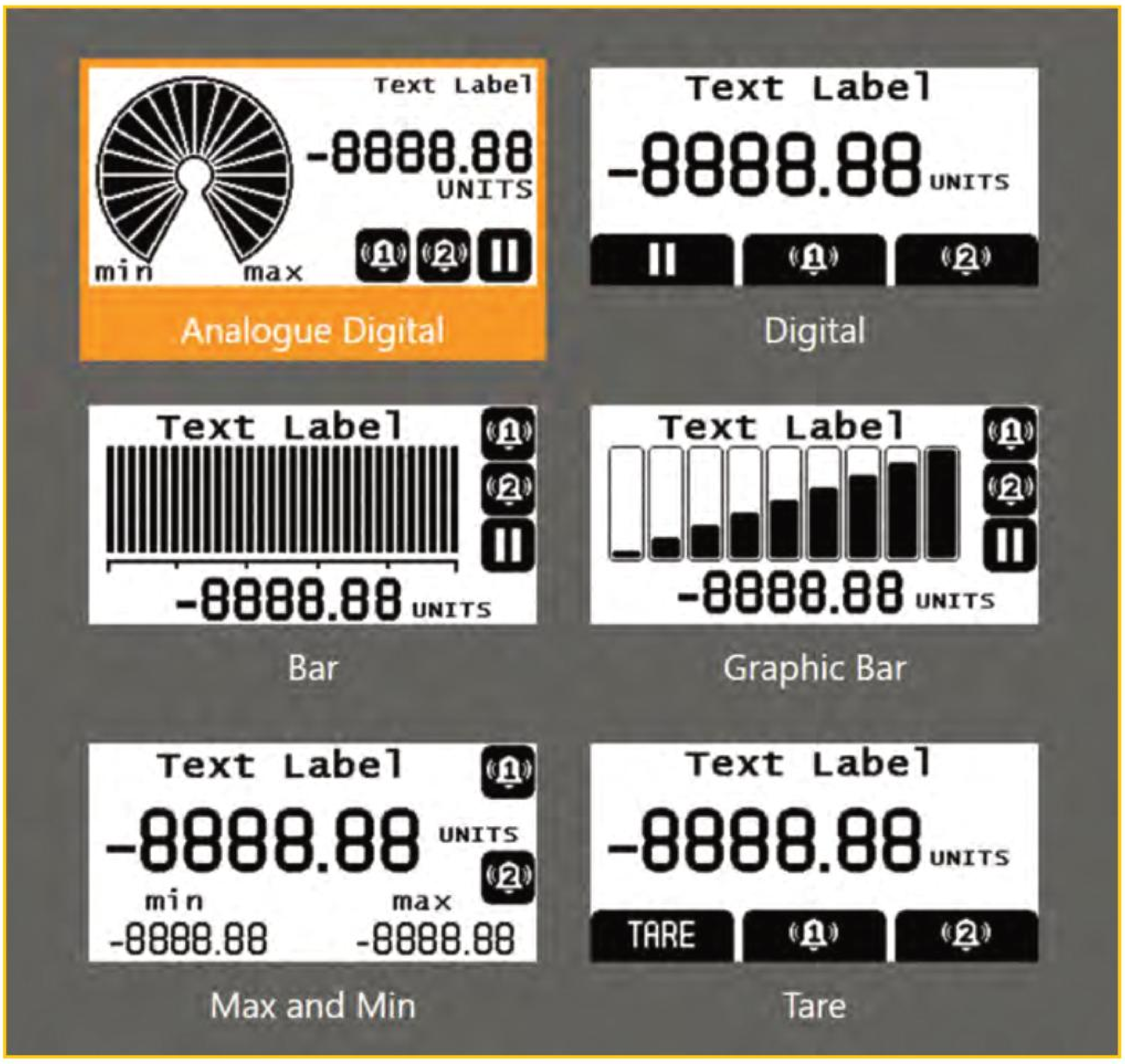

Text Label
-8888.88
UNITS
min
max
Analogue Digital
Text Label
-8888.88 UNITS
Digital
Text Label
-8888.88 UNITS
Bar
Text Label
-8888.88 UNITS
Graphic Bar
Text Label
-8888.88
UNITS
min
max
-8888.88
-8888.88
Max and Min
Text Label
-8888.88 UNITS
TARE
Tare

Fig.2 Six different preformatted displays are available. Each can be custom configured for label, units and scaling.

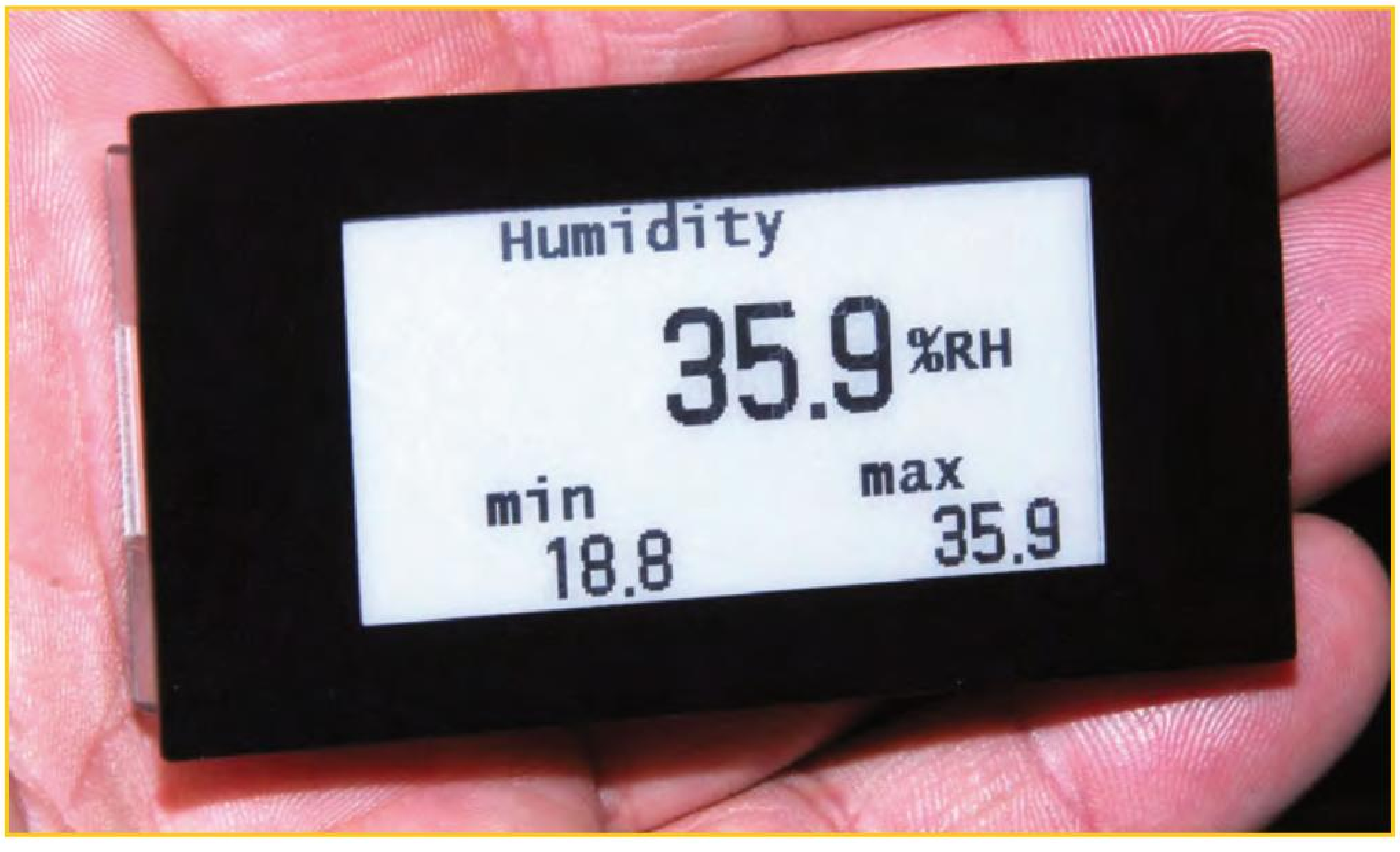
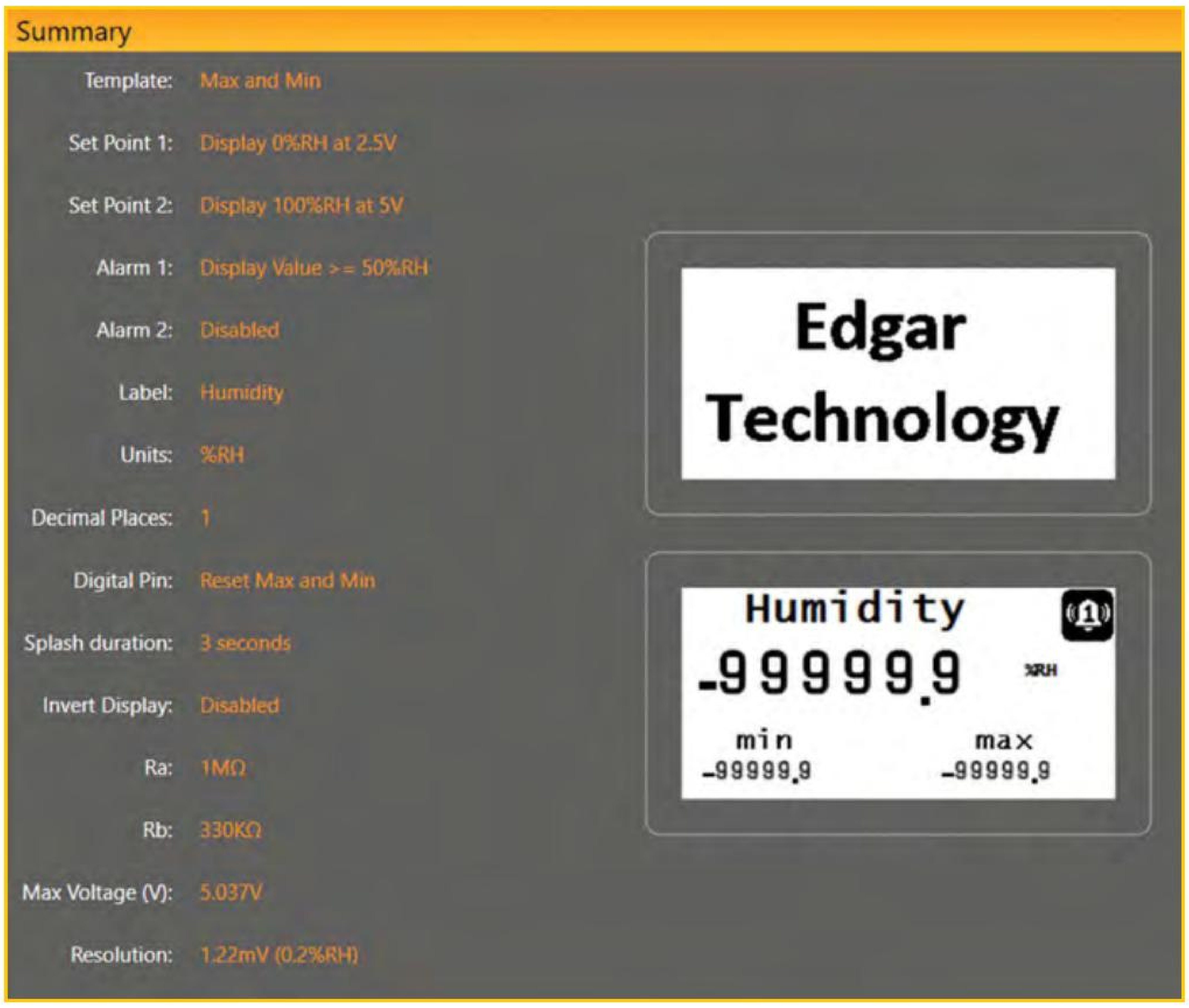

Humidity
35.9 %RH
min
18.8
max
35.9

Fig.1. The PanelPilot voltmeter uses a low-current dot matrix e-paper design that has excellent clarity. The display is configurable via free downloadable software.

Specifications

The meter uses a nominally 70mm (2.1-inch) display with an actual display area of 48.3 × 23.7mm. The meter's direct measuring voltage range is 0-1.25V, but with the placement of two voltage dividing resistors on the PCB, voltages of up to 30V DC can be read. Suitable resistor placement will also allow the meter to directly read up to 200mA. The display updates twice a second and its accuracy is said by the maker to be typically 0.05%, with a minimum of 0.1%.

Three header-pin connectors are located on the back – designated PL1, PL2 and PL3. PL1 is for the USB cable's connector that is used when configuring the meter. This cable must be bought separately, and note that the connector needs to be inserted with the projections facing downwards (nothing prevents the



Summary

Template: Max and Min

Set Point 1: Display 0%RH at 2.5V

Set Point 2: Display 100%RH at 5V

Alarm 1: Display Value >= 50%RH

Alarm 2: Disabled

Label: Humidity

Units: %RH

Decimal Places: 1

Digital Pin: Reset Max and Min

Splash duration: 3 seconds

Invert Display: Disabled

Ra: 1MΩ

Rb: 330KΩ

Max Voltage (V): 5.037V

Resolution: 1.22mV (0.2%RH)

Fig.3. This shows the software configured and about to be uploaded to the meter. 'Edgar Technology' is my chosen splash screen that is set to appear for three seconds. The display is configured to show relative humidity of 100% at 5V input, and 0% at 2.5V input. Note that this screen also shows the resolution (1.22mV, or 0.2% relative humidity) and the required voltage divider resistors.

connector being inserted upside-down). PL2 is for 'simple' meter use – the pins comprise power supply and ground for the meter, and input signal and ground for the measured voltage. PL3 is for more complex meter set-ups. In addition to power supply and signal connections, this connector also includes pins for digital input, an alarm output, and a regulated 3.3V output that can be used to power other devices (up to a maximum of 145mA). The alarm pin is an open-collector output (ie, connects to ground when activated) and can sink 10mA.

The function of the digital pin depends on the meter configuration that has been set. For example, if the meter is configured to sound an alarm, this pin can be configured as an alarm reset button. In other configurations it can be used to set tare (ie, set a zero point), reset the maximum and minimum that is displayed, hold the display, and so on.

Displays

The main advantage of the meter is the versatility in displays that can be shown. Six different types of display are included in the software, from configurations that are just numerically based, through to those with graphs and numbers. Each of the displays can also be reversed (ie, black on white becomes white on black) – I found the black on white displays easier to read. In addition to the overall type of display, the label and units can both be set. For example, you can select 'Temperature' as the label and then select °C or °F for the units. (And if you want to really confuse people, you can select Temperature and then display it in Hz!) Furthermore (and while this wasn't clearly explained in the application notes) you can specify your own labels and units, just by highlighting the boxes and typing.

You can also have an optional 'splash screen' – a screen of text (or an image) that appears for a pre-set time before the display switches to its measuring mode. The display has a 250 × 122 pixel resolution and an image of this size can be uploaded to the meter. For fun, I quickly made an image in Microsoft Paint that said 'Edgar Technology' and uploaded this as my splash image. The text was quite clear, but with 250 × 122 resolution, you're not going to be able to display detailed pictures.

When power is first applied, the meter takes about three seconds to boot up, the display alternating dark/light during this period. If you have a splash screen set for three seconds, the sequence is three seconds boot-up, three seconds splash screen, three seconds boot-up – then the 'proper' display. Therefore, if making quick measurements (eg, via a button press that powers-up the meter) you'd want to dispense with the splash screen. However, the minimum delay before seeing the reading is still three seconds after power-up.

The scaling of the meter can be easily set – an example will show how it works. Let's imagine that you are using a relative humidity sensor that has a maximum output of 5V. First, set the maximum voltage the meter will see to 5V. The required voltage-scaling resistors are then displayed in the software – in this case, 1MΩ and 330kΩ for Ra and Rb respectively. Let's say the sensor outputs 2.5V at 0% humidity and 5V at 100% humidity – and is linear in between. Set these values in the digital scaling output. We want an alarm to sound when the humidity is above 50%, and we want to display the measured humidity and the maximum and minimum values. The digital input pin we configure to have a 'reset max and min' function. Upload this software and the meter is now configured. When connected to the PC, the meter displays the uploaded configuration (no other connections needed), making it easy to check you've got what you want.

Conclusion

I found the meter to perform just as advertised. With its excellent readability, versatility of scaling and range of display configurations, this is an instrument with many applications. The meter is listed at US$49.95 and the USB cable at US$4.95. See: **http://lascarelectronics.com**

Disclosure

The reviewer has no connection with Lascar; the review meter was supplied by Lascar at no charge.

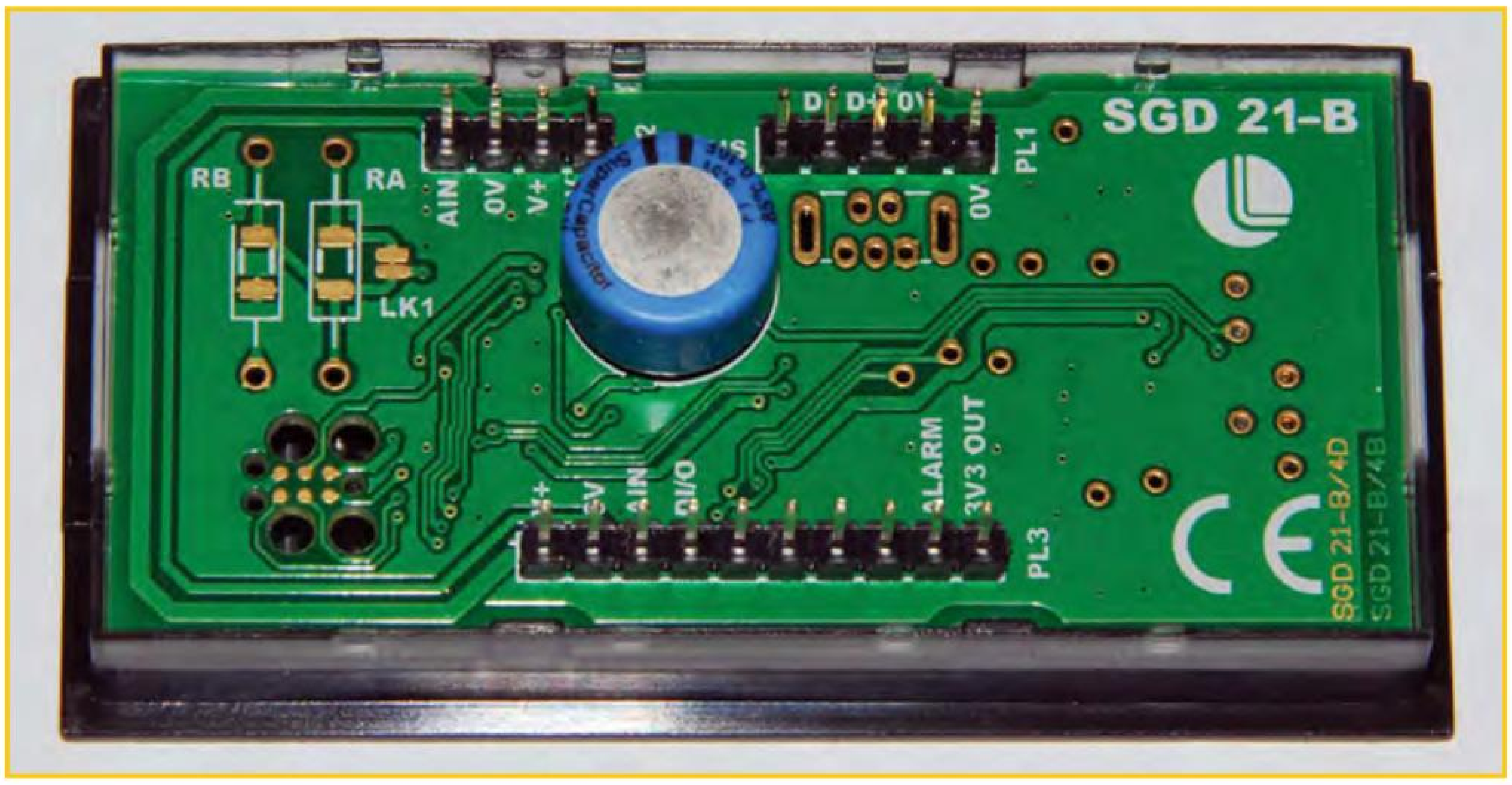


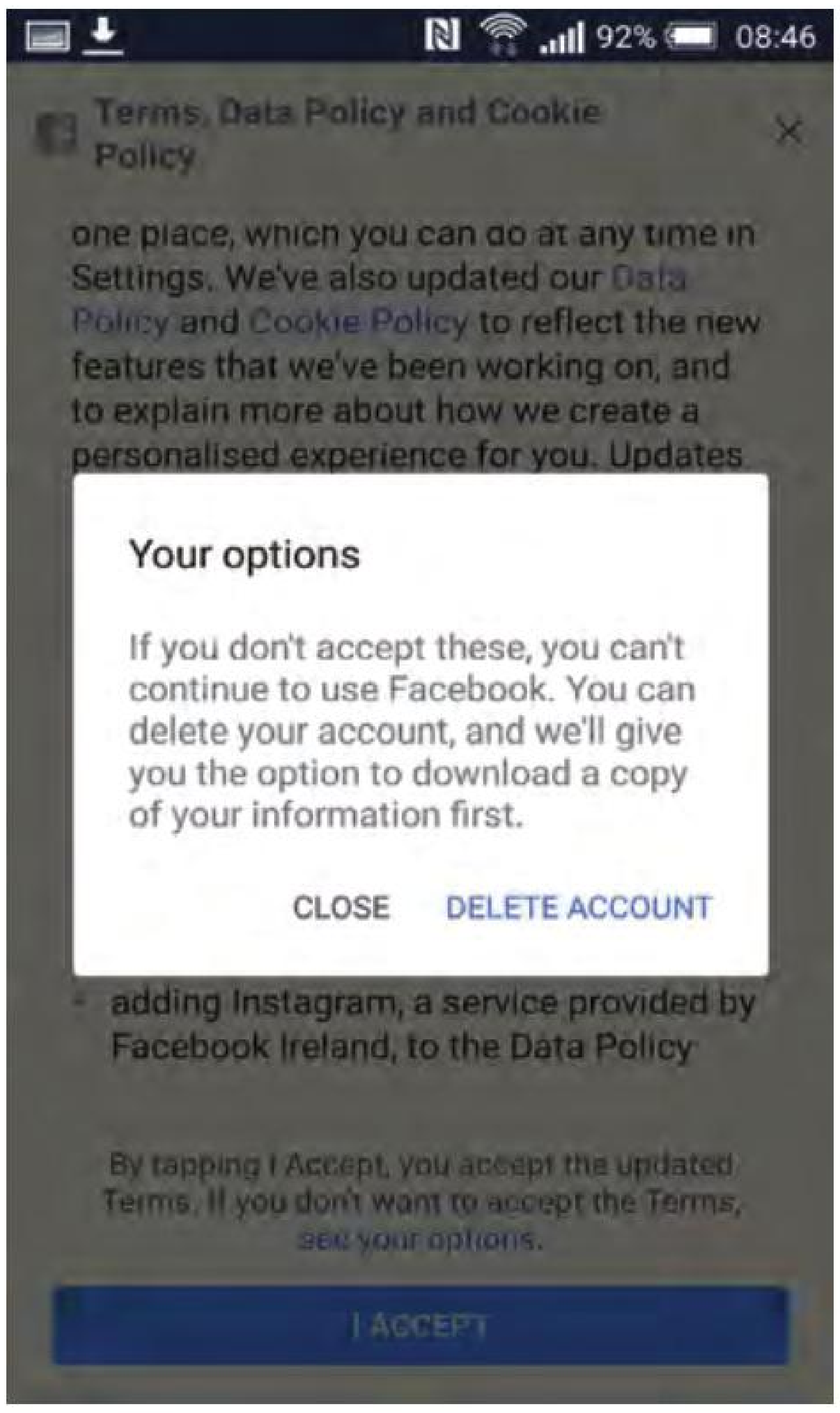
Fig.4. The rear of the meter – at its simplest, just four connections are needed: power and ground for the meter, and signal input and signal ground. Also shown here is the connector for the USB cable and the pads on which the input voltage divider resistors are added, as required.

NET WORK

by Alan Winstanley

Facebook's growing pains

IN Britain, the pub chain JD Wetherspoon recently ditched the entire social media presence for its 900 pubs; the company felt it would be no loss and their time and money could be spent more productively on running the business instead. There is also some evidence that the number of active Facebook users in the US and Canada is starting to dwindle a little. Facebook is currently re-thinking how it could best appeal to its users, and it wants them to spend less time (about 5% as it turned out) on their website, but doing something more productive with that time when they are there. One way has been to reduce the number of viral videos posted onto the platform. Mindful of the traffic enjoyed by Netflix, Amazon Prime and YouTube, Facebook launched its own video platform called Facebook Watch in the US late last year. Facebook will leverage the 'quality interaction' aspect by focussing on friends discovering and sharing Watch videos with each other – in other words, cashing in on the chatter.



one place, which you can do at any time in Settings. We've also updated our Data Policy and Cookie Policy to reflect the new features that we've been working on, and to explain more about how we create a personalised experience for you. Updates

Your options

If you don't accept these, you can't continue to use Facebook. You can delete your account, and we'll give you the option to download a copy of your information first.

adding Instagram, a service provided by Facebook Ireland, to the Data Policy

By tapping I Accept, you accept the updated Terms. If you don't want to accept the Terms, see your options.

Facebook recently forced new T&Cs (terms and conditions) on to its users

Facebook still dominates the Internet news as it tries to diffuse the crisis over lax user privacy and screen out fake news to safeguard non-discerning users. Some 50 million data subjects are said to have had their Facebook profile data slurped by an innocent-looking Android app, a number that has since risen to 87 million and could be higher still as other apps are now being implicated. These are all part of the growing pains that a young, brash and bright-eyed Internet firm might experience, focussing on itself and taking liberties with its userbase thanks to woolly, lax or disingenuous terms and conditions (T&Cs). The founder of Facebook, Mark Zuckerberg, issued a fairly emotionless apology for Facebook's shortcomings before the US Congress, but he refused to submit to questioning by a UK government committee following the Cambridge Analytica data scandal (see *Net Work*, June 2018).

Trying to address personal privacy complaints, Facebook recently pushed through some privacy policy updates that users must accept or face their accounts being closed, as a mobile screenshot shows. However, this was no different from the way many agreements with banks or other institutions are managed. Revised T&Cs come along all the time and loyal customers are given 'Hobson's choice': either accept them by a given date, or you get the 'option' of declining them and closing your account.

Facebook's outline Statement of Rights and Responsibilities runs to nearly six pages of A4 when printed, but a plethora of other conditions surround every aspect of Facebook's services, including some grossly over-simplified (and infantilised) graphical explanations of how Facebook advertising works. Overall, there is a vast amount of policy material littered with naive graphics for the ordinary consumer to digest. I could not find printer-friendly versions of them anywhere.

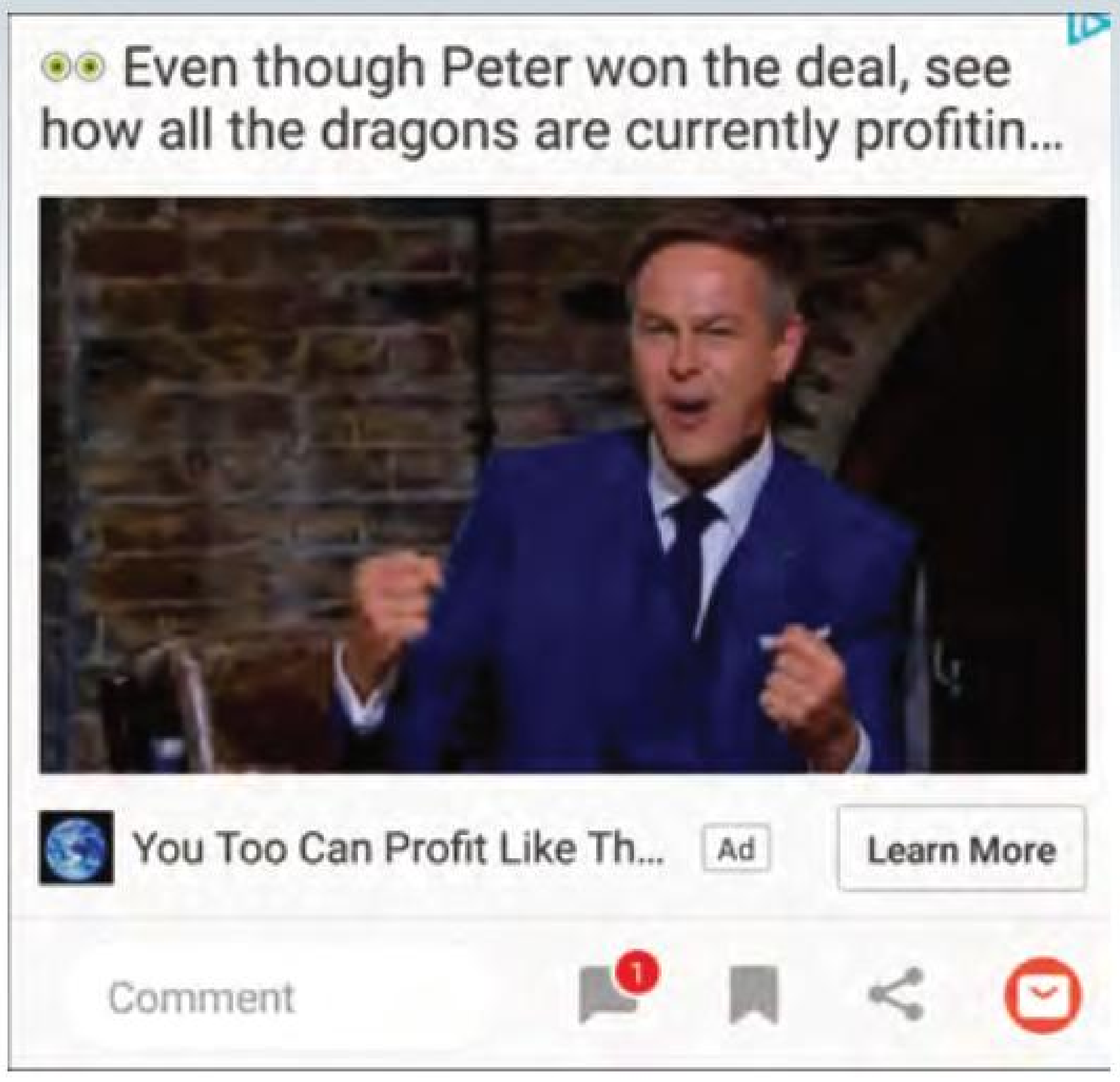
Faked on Facebook

Advertising revenue and affiliate sales are the financial lifeblood of many websites, and despite recent controversies, Facebook's sales revenue continues to spiral upwards, even though the number of DAUs (daily active users) was seen to plateau in some regions. Facebook continues to struggle with phoney advertising posted by bogus 'actors', even though last year it claimed it neither tolerates infringing advertising nor those that use 'cloaking' (enticing adverts that have deceptive destinations, such as health or financial scams).

Within the past few weeks, the author saw a spike in scam adverts posted on Facebook and elsewhere that were extremely convincing and which would have undoubtedly drawn in some unsuspecting victims. Several of them tried to con people into investing in Bitcoin cryptocurrency. One highly authentic-looking advert featured panellists from BBC TV's *Dragons Den* (the UK equivalent of *Shark Tank*). Its professionally written copy included shots of well-known UK entrepreneurs such as Peter Jones and Deborah Meaden, pictured celebrating after supposedly investing in Bitcoins. Fraudulent follow-up testimonials from 'delighted users' added to the credibility. Shockingly, the fraudulent websites are still live many weeks later. For details of this current Bitcoin scam and many others, visit ActionFraud, the UK's national fraud and cybercrime reporting centre, at: **https://preview.tinyurl.com/ybog9uzn**

The UK TV presenter Martin Lewis, a vocal champion of consumer finance and the name behind **MoneySavingExpert.com**, has taken the extraordinary step of suing Facebook. Bogus adverts selling cryptocurrency featuring his photo have appeared on Facebook for more than a year, he claims, with the onus being on him to report them rather than on Facebook to block them at the outset. Examples of adverts are in his blog article at **https://preview.tinyurl.com/y952z96z**, where some readers will recognise brands such as the BBC and *Daily Mirror* newspaper and marvel at how sophisticated the fraudsters have become. Facebook is increasingly using AI systems to sniff out bogus ads like these.

His blog's feedback section includes claims that some punters were suckered in by the supposed endorsements made by Lewis, and they lost money as a result. As they


Even though Peter won the deal, see how all the dragons are currently profitin...

You Too Can Profit Like Th...

A bogus Bitcoin ad featuring a TV program panellist

say, a fool and his money are soon parted, and in this case I'm afraid I have mixed sympathies given that their motivation (like the scammers) was always to be greedy and make lots of money. It has never been truer that if something doesn't pass the 'sniff test' then you should trust your gut instincts, which are often much better honed and more powerful than you might recognise, and steer well clear of any offers or ads that somehow just don't seem quite right.

GDPR: Data Protection's big guns

The elephant coming down the privacy pipeline for the past two years has been the EU's General Data Protection Requirement – GDPR. This is the EU's redesigned and totally unforgiving privacy regulations that puts a citizen's personal data privacy front and centre where it rightly belongs. Designed to protect the data of all EU citizens from misuse by corporations located anywhere in the world, it also promises to put a stop to legalese and reams of indigestible terms and conditions, as the sign-up or approval to use private data must be done in an accessible manner. The citizen's so-called 'right to be forgotten' is also strengthened.

The GDPR is impacting online services in a multitude of ways, including the domain name WHOIS lookup system. In the case of dot-com and other top-level domains (TLDs) it has usually been possible to run a WHOIS look-up of user details and retrieve their address and phone number; useful when combating copyright infringement or other fraud. Hence the success of Go Daddy's Privacy Protection or Namecheap's WHOISGuard and similar paid-for services that hide personal domain name details from public view.

ICANN, the body overseeing the management of domain names is in desperate trouble over the GDPR and the impact it will have on the WHOIS database. Showing no sign of compliance in time for the EU's deadline of 25 May, ICANN has asked the EU for a stay of execution, which seems highly unlikely to be granted. By the time you read this, the GDPR will be legally in place across Europe and the domain name WHOIS look-up system risks being broadly incompatible with its core principles.

Thanks to the GDPR, readers have probably received a barrage of T&Cs updates from various online services recently, all proclaiming that 'your privacy is important to us', as they bounce us into accepting yet more terms and conditions, this time hopefully with tougher privacy safeguards in mind. Expect to hear much more about the GDPR in coming months and years as its effect on electronic databases that include you and every other web user gradually materialise.

That's all for this month's *Net Work*. You can contact the author at **alan@epemag.net** or write to the editor with your views for possible inclusion in Readout, at **editorial@wimborne.co.uk**

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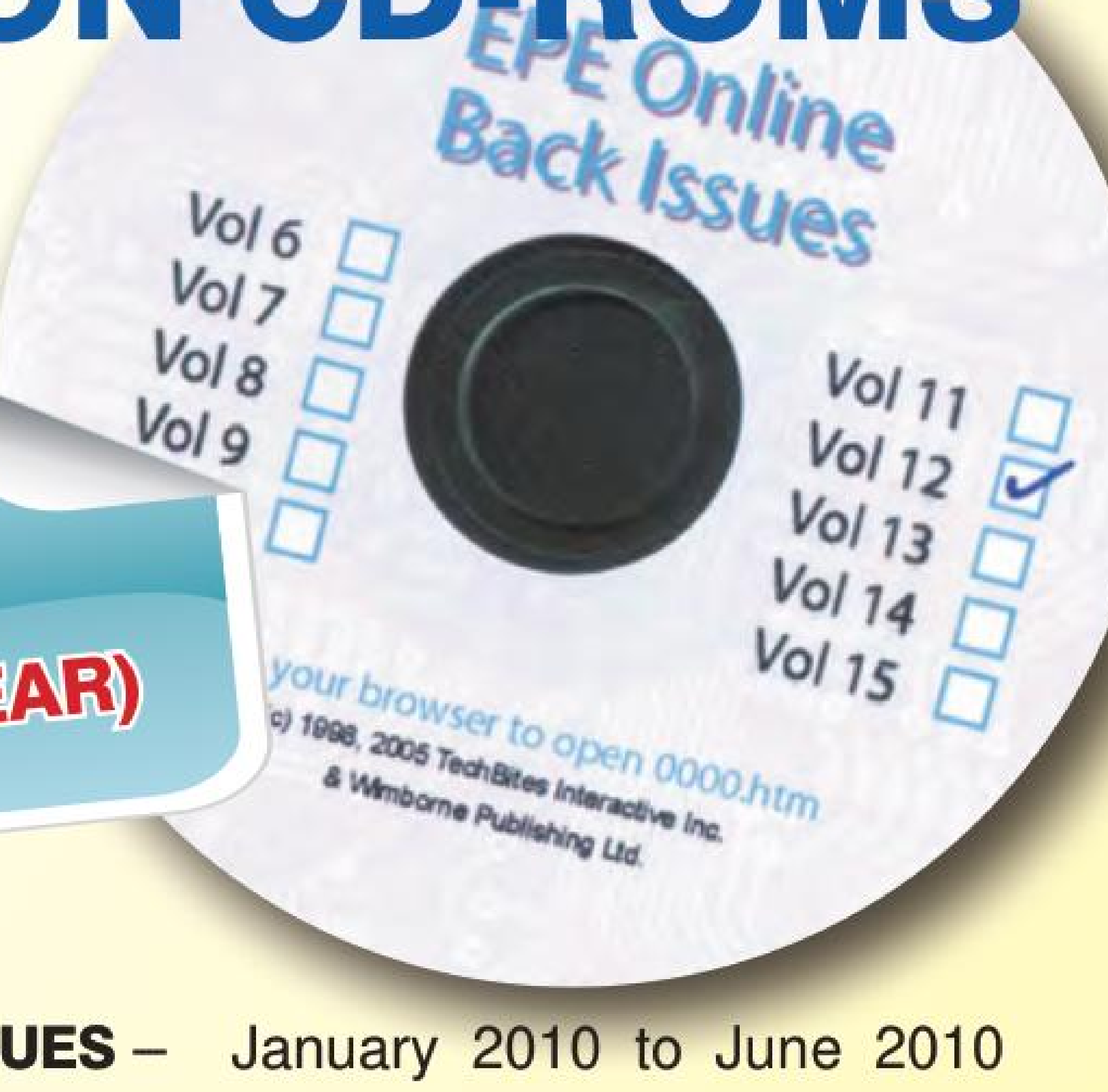
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PIC n' Mix

Mike Hibbett

Our periodic column for PIC programming enlightenment

Practical DSP – Part 4

In this fourth article on DSP (digital signal processing) techniques, we complete our mini-project on the application of the Fast Fourier Transform (FFT) algorithm to create a simple guitar tuner. If you have missed the previous three *PIC 'n Mix* articles then fear not, as the full schematic is shown this month, and the source code is freely available to download from the magazine website. However, the previous three articles provided a step-by-step approach to setting up the Microchip tools and an overview of the DSP algorithm we have been focusing on, so they are well worth reading.

Last month, in *Part 3*, we succeeded in integrating a low-cost electret microphone with the dsPIC's on-chip op amp, with minimal external components applied. This brings a nicely amplified audio signal into the processor. This month, we complete the steps outlined in last month's article by configuring the ADC to take samples and pass them to the FFT function.

We will take 512 ADC samples of the audio signal at a sample rate of 2kHz, giving us the ability to resolve signals up to 1kHz. Guitar strings resonate at a lower frequency than this, and we will be looking for a frequency of 110Hz, the frequency of the 'A' string on an acoustic guitar. As we have two LEDs in this design, we will illuminate the second LED when the A4 note is sounded, at a frequency of 440Hz.

Unfortunately, it's not possible to configure the ADC peripheral to take these 512 samples automatically, so we will configure a timer to run at 2kHz, which will trigger a timer interrupt routine to be called every 500µs. This interrupt routine will do nothing more than start the ADC conversion. Once the ADC sample completes, an ADC interrupt routine will be called, storing the sample in a buffer. If the buffer is full, it will copy the contents of the buffer to a second buffer and set a 'flag' variable that will tell the main loop application to perform the FFT. While the main loop waits for the buffer to fill, it places the processor in a 'Halt' state, minimising the noise in the circuit while the samples are being taken.

Our application is now going to consist of several parts, or 'tasks', all able to run concurrently.

You may be wondering why the buffer, once full, gets copied to another buffer and handed off to the main application. It appears to be a waste of a scarce resource. In fact, this is simply an efficient way to use the processor. Rather than perform the tasks in series, we can allow the sampling of ADC samples to run at the same time as the FFT routine, if required. Essentially, the FFT and subsequent displaying of data will get briefly interrupted while the ADC and timer interrupts are called. These interrupts are very quick, and do not significantly delay the transform calculation. Interrupts enable us to interleave operations to make the overall process quicker. Interrupts do add a little more complexity than a simple 'main loop', but they are worth it for the increase in performance. As a result of copying the data to a second buffer the FFT routine will process that information while the timer and ADC interrupt start filling the first buffer. In this way, we ping-pong between two buffers – as one is being filled, the other is being processed. As the capture of a buffer's worth of data by the ADC takes far longer than the FFT algorithm and display code, we never 'overrun' the available time. Knowing these timing relationships – by calculating how long it will take to fill a buffer, and how long it will take to process that buffer – enables us to significantly reduce the complexity of the software. The main application processes the data; the interrupt routines collect the data. We are sampling data at a rate of 2kHz, so 512 samples will take just over 256ms to collect. That means we have 256ms in which to perform the FFT function and display it. More than enough time, even if we are writing to an LCD display.

Completing the code

Once again, we list the things we need to do – one by one – so we can tick them off as we go along. (This is what is known in the profession as 'the high-level design'). Here is what we need to achieve:

- Configure the ADC to use the op amp input for sampling
- Write an ADC interrupt routine to store the value in a buffer
- Configure a timer to run at 2kHz
- Write a timer interrupt routine to start the ADC conversion
- Update our main loop to wait for the ADC buffer to become available
- Turn on the LEDs when 110Hz is detected as the strongest signal

Configuring the ADC

This is almost certainly the hardest part of the design. As we have mentioned earlier, the ADC is one of the most versatile peripherals, and this versatility brings complexity. Coupled with the need to wade through that complexity is the requirement to follow the generic ADC guidelines:

- Allow the ADC sufficient time to sample the input signal
- Wait for the conversion of that signal to complete

Let's explore what that first point means. The analogue-to-digital conversion process follows several well-defined steps. First, the input signal is connected to a capacitor inside the ADC peripheral, and it takes time for that capacitor to charge up to the voltage that has been presented to it. How long it takes depends on the impedance of the signal driving the ADC input pin. If that signal has high impedance, then it takes longer than if it were low impedance. This should be obvious, as a resistor and a capacitor have a natural RC time constant. The problem is, if we allow too much time for the capacitor to charge, then we end up taking longer than our sampling time. Consider an extreme case: if you were trying to measure a 1kHz tone, would you allow one second for the capacitor to charge? Of course not; so, there is a balance that needs to be determined, and unfortunately only you the designer of the circuit hold the answers.

The input impedance is a key parameter when you are trying to measure signals that change amplitude quickly with time, as our samples are. You have just two variables to play with: the impedance of the signal driving the ADC input pin, and how frequently you need to sample. We have already chosen a sampling frequency, 2kHz. This means that our upper bound for sample acquisition and conversion time is 500µs. We would like it to be much less than this, to minimise the impact of the signal's changing values. So how about the input signal impedance? Here, we are in luck. Because our signal will come from the output of an op amp, we know that op amp's have a low output impedance – typically below 100Ω. While the dsPIC's op amp is uncharacterised in the datasheet, we can probably start by assuming it's around 100Ω and see where that takes us.

Let's go ahead and configure the ADC. The key document to help us here is the ADC section of the *dsPIC33E/PIC24E Family Reference Guide*, available from the link in Ref. 1 at the end of this article. Section 16.2 lists the registers involved in configuring the ADC – nine of them! The ADC reference guide is 96-pages long, which seems daunting, but we can minimise how much of it we need to read by noting the specific features we will be using:

- Sample size of 12 bits only
- A single input channel will be sampled
- The input is OP-AMP2, not an input pin
- ADC conversion occurs while in IDLE mode
- The ADC Interrupt must be enabled

Why use 12-bit samples rather than 10? The 10-bit sampling options allows for faster sampling rates, but since the 12-bit version supports 500KB/s, that is more than fast enough, so we choose to gain the extra two bits of precision. It will not impact the FFT calculation time because the algorithm expects 12-bit precision anyway.

In 12-bit mode we can only use channel 0 within the ADC, as explained in Figure 16-2 of the ADC reference manual (you really do have to read all the documentation to find these 'Gotchas'!) Fortunately, this limitation does not impact our circuit design or the performance of the project.

Now we add the set-up code for the ADC. This can go in our main routine, just after the op amp configuration (Listing 1).

Listing 1

```
// Auto convert, 12 bits
// Fractional data
AD1CON1 = 0x07E0;
AD1CON2 = 0x0000;
// Internal ADC osc
// mid-range sample time
AD1CON3 = 0x8F00;
// DMA disabled
AD1CON4 = 0x0000;
// Use Op-amp2
AD1CHS0 = 0x1919;
AD1CHS123 = 0x0000;
// No scanning
AD1CSSH = 0x0000;
AD1CSSL = 0x0000;

// Enable interrupt
IFS0bits.AD1IF = 0;
IEC0bits.AD1IE = 1;
INTCON2bits.GIE = 1;

// Start the ADC
AD1CON1bits.ADON = 1;
AD1CON1bits.SAMP = 1;
```

ADC Interrupt

We now move on to the ADC interrupt routine. This is a 'C' function that will be called by the processor directly when the ADC conversion completes. *The MPLAB XC16 C Complier Users Guide* (accessible from the 'Compiler Help' button in the MPLAB IDE) explains how this function should be created. It is an interrupt routine, so it has a slightly different format to a normal 'C' function (Listing 2).

We don't need to understand what all those strange attribute labels mean; modifying those is an advanced topic that we do not need to worry about for a simple project like this. It is, however, important to create the function exactly as shown below, because the compiler 'knows' that the function named `_AD1Interrupt` should be the function called when the 'ADC Complete' interrupt fires.

Recall what we need this interrupt routine to do:

- Read the ADC value
- Divided that value by two
- Store the value in a buffer
- Copy the buffer when full
- Flag the main loop when full

To do this, we will need to create some new variables at the top of the program, not inside the interrupt routine, so that they can be accessed by both the interrupt routine and the main loop application. The complete code is shown in Listing 3 below.

Note how the global variables have been marked with the volatile attribute. This is a hint to the compiler that these variables may be modified within an interrupt routine. If we didn't use this attribute, the compiler will get very confused, especially with our `bufferFull` variable, which we will use later in our main loop.

Timer Interrupt

If we were to run this code now, as shown above, it would run once. It would buffer one sample, and then stop. We now need to create a very simple timer interrupt that will fire off at our sample rate, to trigger ADC sampling at the desired rate – 2kHz, or once every 500µs. Thankfully, the timer peripheral module is a much simpler peripheral than the ADC. There are five timer modules on this processor, and we will use the simplest one – Timer1 – which is a 16-bit timer.

The operation is simple: the timer counts up from zero until it reaches a value that matches the value held in the PR1 register. When it reached that value, the timer resets to zero and triggers the Timer1 interrupt. The input clock to this timer is the system clock, running at 70MHz. At this frequency, 35000 tick-tocks of the clock will take 500µs. So, we program the PR1 register to that value,

Listing 2

```
void __attribute__((interrupt(auto_psv))) _AD1Interrupt(void){
   // do your stuff here

   IFS0bits.AD1IF = 0;
}
```

Listing 3

```
volatile fractcomplex adcBuff[FFT_BLOCK_LENGTH];
volatile uint16_t bufferIndex = 0;
volatile uint16_t bufferFull = 0;

void __attribute__((interrupt(auto_psv))) _AD1Interrupt(void)
{
    fractional val;

    val = ADC1BUF0;
    adcBuff[bufferIndex].real = val >> 1;
    adcBuff[bufferIndex++].imag = 0;

    if (bufferIndex == FFT_BLOCK_LENGTH) {
        bufferIndex = 0;
        memcpy(sigCmpx, adcBuff, sizeof(sigCmpx));
        bufferFull = 1;
    }

    IFS0bits.AD1IF = 0;
}
```

and enable timer interrupts. Below is the initialisation code that can go in the main function, just after the ADC initialisation code:

```
PR1 = 35000;
IFS0bits.T1IF = 0;
IEC0bits.T1IE = 1;
T1CONbits.TON = 1;
```

Now, as before, we need to create a timer interrupt routine (Listing 4).

Listing 4

```
void __attribute__((__interrupt__, no_auto_psv)) _T1Interrupt(void)
{
    IFS0bits.T1IF = 0;
    AD1CON1bits.SAMP = 1;

    // test code
    LATB = ~LATB;
}
```

We've added a line of code at the end of the routine to test that it is being called, and at the correct frequency. You can place a breakpoint in the interrupt routine to check it is being called, but toggling a pin and then viewing the signal on that pin with an oscilloscope allows us to be certain that this is being called once every 500µs. It was interesting to note that the frequency is 1.84kHz, not 2kHz as we had calculated. This is because we are using the on-chip RC oscillator for our processor clock source, and it's not calibrated to exactly 70MHz, but a little lower. On re-reading the datasheet we found that the RC oscillator runs at approximately 7.37MHz, not 8MHz as assumed. We could spend time calibrating the RC oscillator, but instead changed the PR1 count down to 32200, which gives the desired 2kHz sample rate.

Completing the application

After making the above changes and some slight modifications to the original code – changing the sample rate from 10000 to 2000 and fixing a bug with the calculation of the peak frequency – we are ready to get the FFT function running with our real-world data. Two lines of code were added at the end of the main loop to provide illumination of the LEDs, with Pin 15 going high when the note A2 is played, and pin 16 going high when note A4 is played. The response to a real guitar was quite good, with the tuning being detected from a few feet away, even in the presence of noise. We could show you a picture at this point, but an LED turning on is not terribly interesting!

Now is a good time to check how much code and data space we used within the microcontroller. This is shown in the 'dashboard' tab of the MPLAB IDE. Just 1% of code space, and 9% of data space – leaving plenty of room for more complex applications. And how much processing time is this application taking up? We know from last month that the FFT algorithm takes 1ms, but it takes 256ms to collect the 512 samples, at a 2kHz sampling rate. Those samples are performed in the background by two very short interrupt routines (the ADC, and the timer) and so we effectively have about 254ms of available processor time in every 256ms 'window'. The CPU is effectively idle for most of the time, which means we can do a lot of additional analysis and data processing during this idle time, while still having a display update rate of 4Hz.

Adding graphics

With the primary design completed let's move onto a somewhat more visually appealing representation of the FFT – displaying the full output of the function on an LCD. With 254ms of processing time available to us, this should be more than enough time to display the content of each frequency 'bin' on a small graphics LCD, giving a spectrum analyser view of the audio signals in the range of 0Hz to 1kHz. While not required for a guitar tuning application, it will be fun and could form the basis of more practical or educational applications – especially when we revisit this project later in the year and experiment with other FFT algorithms, such as digital filters.

Adding a display introduces some challenges. We need a display panel that can interface with a small microcontroller and operate from a single 3.3V supply. It should also be cheap, and readily available.

We've covered graphics LCDs before in *PIC 'n Mix*, so finding a suitable device is straightforward. Most graphics LCDs are 3.3V devices (to the annoyance of Arduino users, whose boards are mostly of the 5V type) and prices have continued to fall over the years. Displays with a viewing size of 2.2-inch appear to hit the 'sweet spot' in terms of cost, availability, and the availability of information on how to drive them. This situation will probably change over time, but as hobbyists we always seem to hit a hard stop with technology – bigger displays are available, often at lower cost, but come with difficult to solder connectors and no datasheet availability – such as displays designed for mobile phones. It's often frustrating to find that better technology is available at lower cost but is in-accessible to us hobbyists due to a lack of data or hard-to-solder connections. That, unfortunately, is the consequence of mobile telephone technology. In some respects, we hobbyists must live behind the curve, rather than at the front. Displays with a 2.8-inch and 3.2-inch viewing size are available in hobbyist friendly pin-outs but we have yet to explore the software support provided. Their prices are quite good, around £7 to £10, so they're likely to be a target of future articles. For now though, we'll stick with the far more popular 2.2-inch graphics displays, based on the ILI9341 controller.

Graphics LCD panels consist of essentially two components – the TFT LCD glass, and a controller chip. The controller chip is the key component for us, as it is the device with which we communicate. The ILI9341 controller has an SPI interface and an internal RAM buffer to hold the contents of the display. All the timing and high-speed communication to the LCD glass are managed by the controller; we do not even need to supply a clock to the module. Just power, an SPI interface and a few GPIO control pins complete the circuit.

The display we are using, called the TJCTM24024-SPI, has a resolution of 320 × 240 RGB pixels and is available from several sources on eBay for £4 to £5. It's worth getting one that looks the same as ours – see Fig.1 – as these are 'generic' displays made by different manufacturers. It's possible

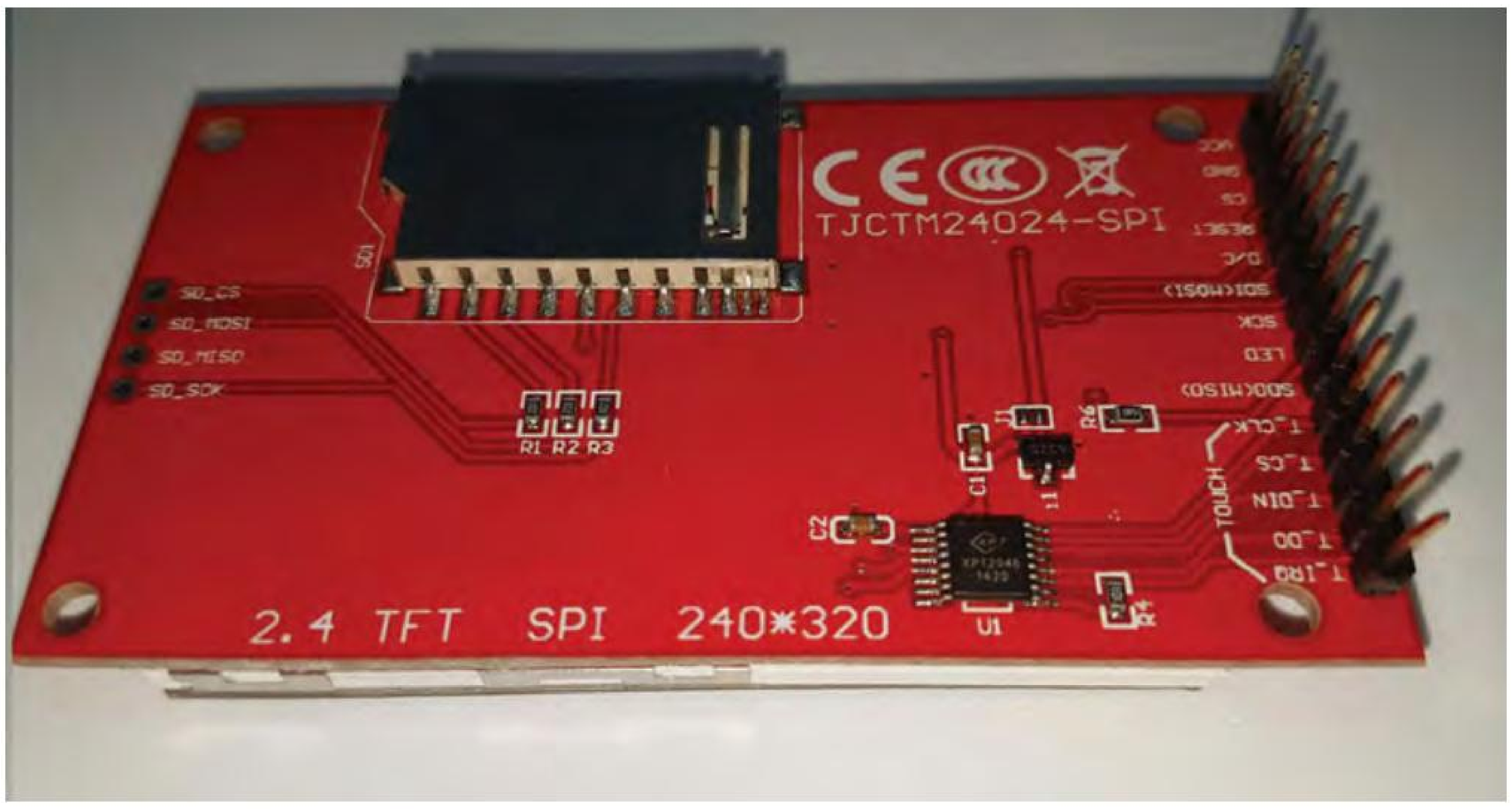

Fig.1. DSP guitar tuner LCD panel, rear view

to purchase a similar device from a more regular electronics supplier such as Adafruit, Sparkfun or Farnell, but the cost will be significantly higher. (A final study of LCD panels available on eBay just prior to publication of this article has shown that similar display panels based on the ILI9341 controller are now available in 2.8-inch and 3.2-inch formats, with the same resolution. It will be very interesting to see whether these larger panels work 'out of the box' with this month's project.)

If you decide to build a project with an LCD, you should plan to use a good power source for the circuit, such as 4 AA cells driving a 3.3V LDO regulator. While the display does not consume a great deal of energy, the backlight will draw close to 10mA, and will deplete two AA cells quickly. We used 4 AA cells and a 3.3V low drop-out regulator (TLV2217-33KCSE3, Farnell part number 2492359.) It's in a TO-220 package, so it's easy to add to the breadboard. For simple tests, two AA cells work fine; they just won't run for very long.

Our screen has an embedded resistive touch screen interface on top of the LCD and an SD Media card interface, but for this stage of the project we will ignore those additions and focus on simply displaying the output of the FFT algorithm.

Connecting this device with our breadboard requires six control signals – three for the SPI bus, and three GPIO outputs for chip select, data/command and reset. While it might seem challenging to add so many signals at this point in the design, Microchip have made it easy for us – the SPI bus can be mapped to any GPIO pin (within limits, as we found later.) Referring to last month's schematic you will see six unused GPIO signals on the processor, pins 21 to 26. So, hooking up the display is simple, and requires just a few lines of code to map the SPI bus to the required pins. Thank you Microchip!

We will want to run the SPI bus as fast as possible, but experience has shown that the limiting factor to how fast we run the interface will be the length of the wires connecting the screen to the breadboard. We are using regular male to female hook-up wires, about 150mm in length. When this design moves to a PCB with shorter interconnect we will be able to run the display somewhat faster as the capacitance on the wires will be lower and interfere with the signals less. It's a point worth remembering for later, as graphics displays require the transfer of a large amount of data, and frequent updates of the display.

The final schematic incorporating the graphics display panel is shown in Fig.2. Please note that the pin order shown for the LCD in the schematic is not in the same order as on the LCD panel PCB itself, so take care to follow the connection diagram when hooking the breadboard and the LCD panel together – *follow the names of the LCD signals shown*.

We have not used this LCD driver chip before, but a search of open-source projects found a driver provided by Adafruit for one of their displays. The software is released under the BSD licence, so we are free to modify and re-use it, which we do. The modifications are mainly in the lower levels of the code that deal with SPI communications and GPIO pin control, as this code was designed to work with a completely different processor. Thankfully, the code is well written, and once those hardware dependences were resolved, the actual LCD initialisation and graphics primitives worked 'out of the box'. For this project, we use just a small fraction of the capabilities in the original driver, but we'll explore more of its features in future articles. For this project we have ported just the line drawing and bitmap display functions.

Porting the code

The LCD panel provides an SPI interface, one of the simplest interfaces offered. The three connections for the SPI bus – data in, data out and clock – are supplemented by three further control signals. Adding these connections still leaves our processor with seven unused processor pins, or nine if we discard the LEDs. So that leaves plenty of expansion capabilities for later.

One limitation we do have is that we cannot use the SPI1 peripheral, since the pinout of that peripheral is fixed, and we are already using those pins. The second SPI module's pin mappings are dynamically assigned, enabling us to conveniently map all the LCD control signals to the six free pins on the right-hand side of the processor. It was pleasing to find that despite the long wires, we were able to run the LCD at a very high clock speed, such that the full display update takes less than 100ms to complete, which is excellent for such wiring.

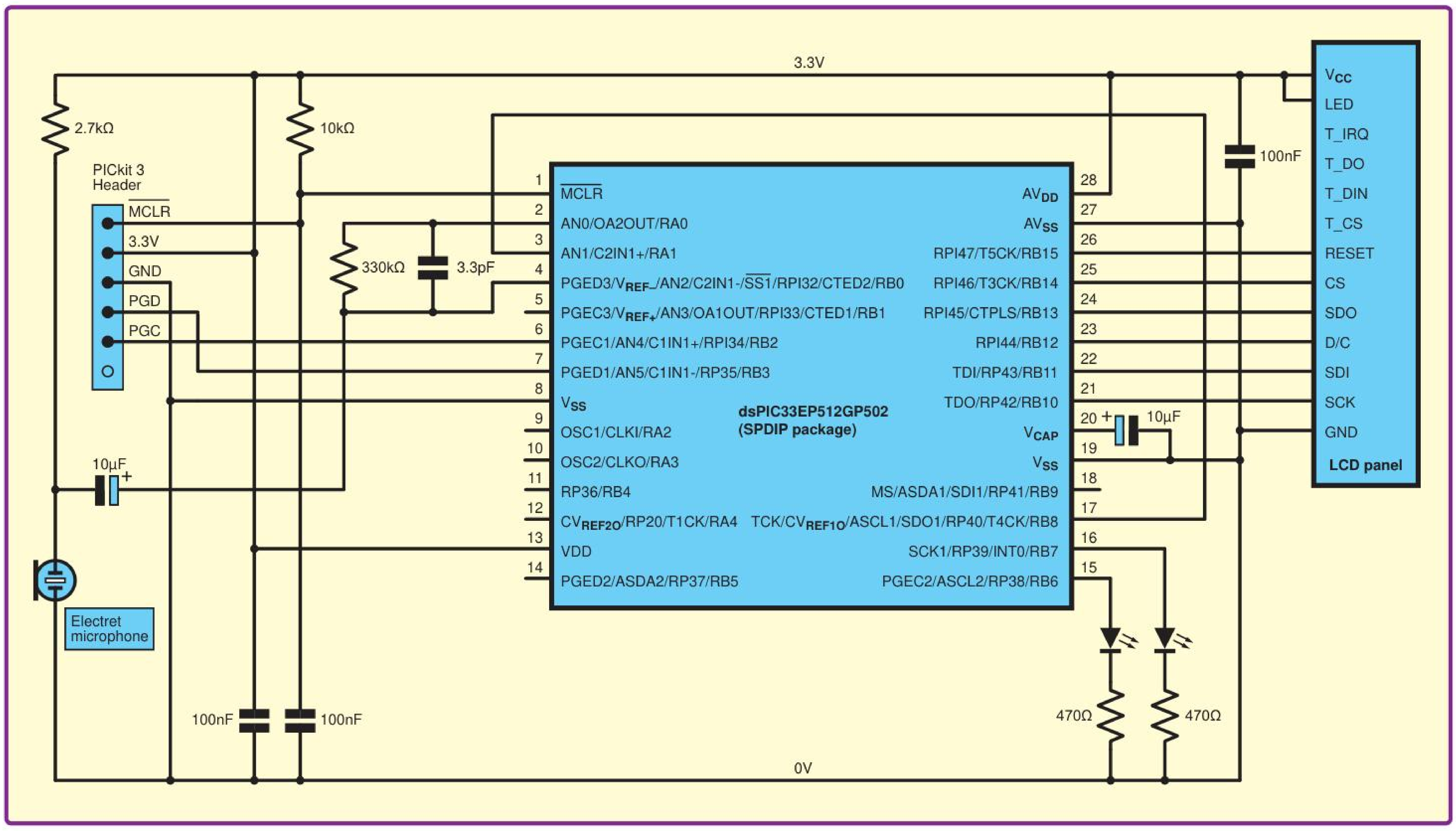
3.3V
2.7kΩ
10kΩ
PICkit 3 Header
MCLR
3.3V
GND
PGD
PGC
330kΩ
3.3pF
10µF
Electret microphone
100nF
100nF
0V
MCLR
AN0/OA2OUT/RA0
AN1/C2IN1+/RA1
PGED3/VREF-/AN2/C2IN1-/SS1/RPI32/CTED2/RB0
PGEC3/VREF+/AN3/OA1OUT/RPI33/CTED1/RB1
PGEC1/AN4/C1IN1+/RPI34/RB2
PGED1/AN5/C1IN1-/RP35/RB3
VSS
OSC1/CLKI/RA2
OSC2/CLKO/RA3
RP36/RB4
CVREF2O/RP20/T1CK/RA4
VDD
PGED2/ASDA2/RP37/RB5
AVDD
AVSS
RPI47/T5CK/RB15
RPI46/T3CK/RB14
RPI45/CTPLS/RB13
RPI44/RB12
TDI/RP43/RB11
TDO/RP42/RB10
VCAP
VSS
MS/ASDA1/SDI1/RP41/RB9
TCK/CVREF1O/ASCL1/SDO1/RP40/T4CK/RB8
SCK1/RP39/INT0/RB7
PGEC2/ASCL2/RP38/RB6
dsPIC33EP512GP502 (SPDIP package)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
28
27
26
25
24
23
22
21
20
19
18
17
16
15
10µF
100nF
470Ω
470Ω
VCC
LED
T_IRQ
T_DO
T_DIN
T_CS
RESET
CS
SDO
D/C
SDI
SCK
GND
LCD panel

Fig.2. Schematic of the DSP guitar tuner

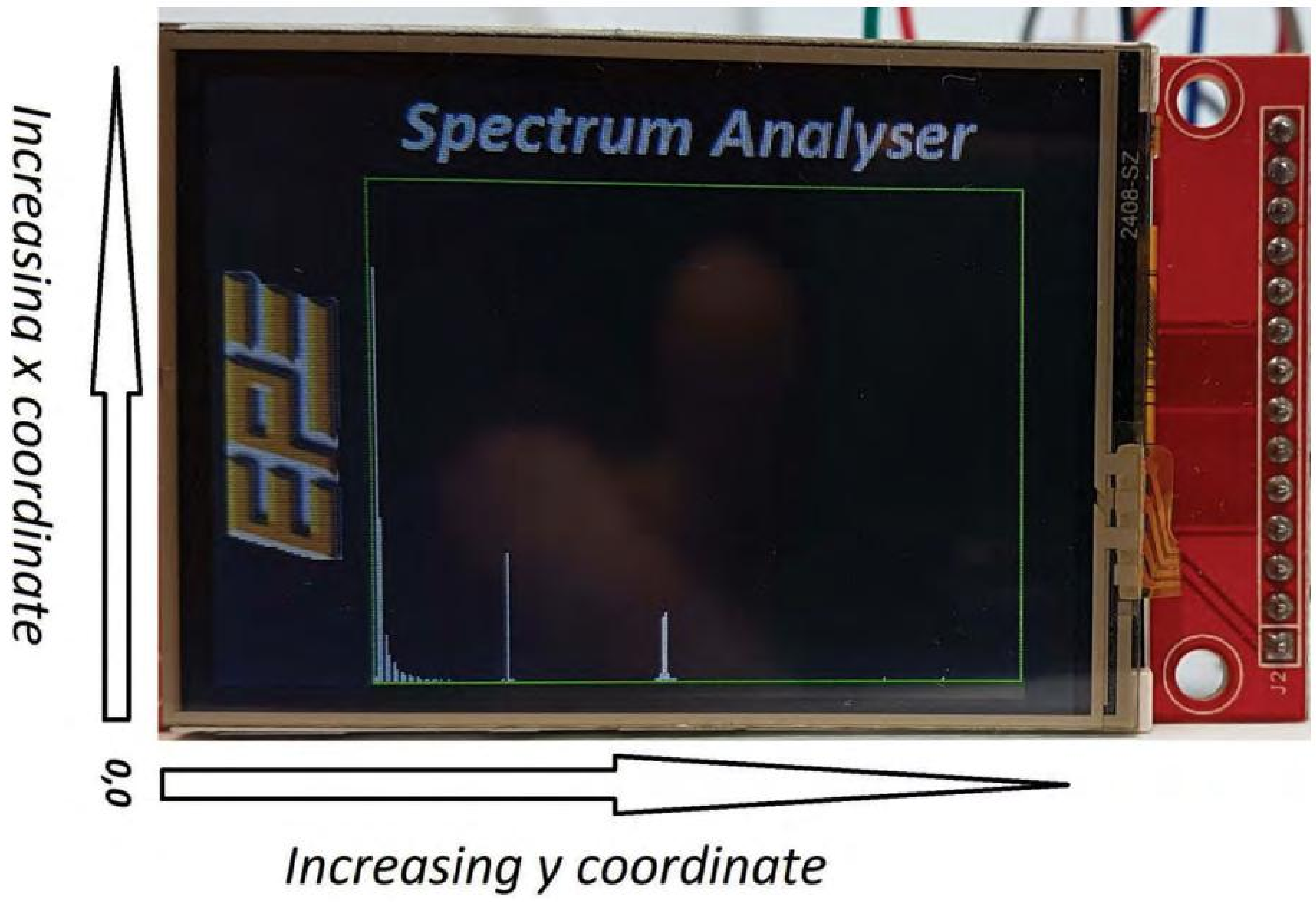

Fig.3. LCD drawing coordinate system

It took a degree of trial and error to establish the coordinate system of the LCD; with no data available on the module itself, we simply drew some test lines and looked at where they came out. The actual orientation of the display, based on the driver code that we ported, can be seen in Fig.3.

From this point it was a very simple task to take the array of 256 'bins' of frequency power magnitude data and write it to the display. For simplicity, we simply clipped any values that were larger than could be displayed. No automatic scaling features were used, that can be a feature for future enhancements. Fig.4 shows a snapshot of the display while we played two tones over a PC speaker.

The spectrum display, pretty as it is, also gave us an immediate epiphany. As we mentioned in a previous article and demonstrated in a simulation of the FFT algorithm, the DC offset on the audio going into the ADC causes large signals to appear at the bottom of the frequency range. These signals block our preferred signal being detected as the peak, until our signals become stronger than the 'false' signals at the low frequencies. A very simple solution to this and an improvement to the sensitivity of the guitar tuner would be to ignore the 'bins' at the lower end of the frequency range, below approximately 50Hz. It would appear that visualising the data has been valuable after all!

Blanking out those lower bins makes the device so sensitive it can detect the *A* string on a guitar being played from across a room. This is probably more sensitive than is required, but it's a really rewarding result.

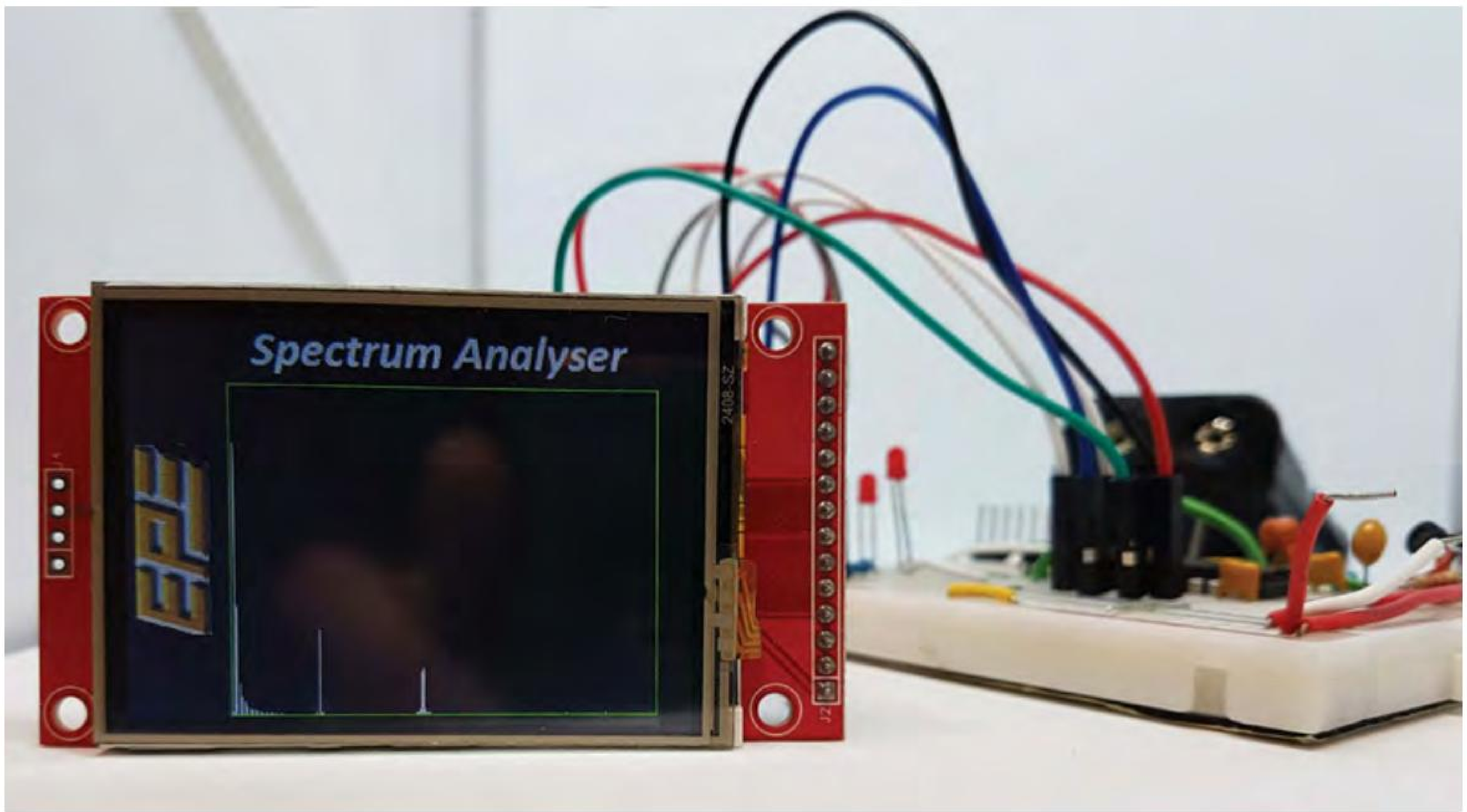

Fig.4. Example display for the DSP guitar tuner

Power consumption

With the LCD active, the circuit draws just 8mA on average, 5mA of which is the LCD backlight. This make the design very suitable for battery powered projects so long as a power switch is added. Again, we would recommend using four AA batteries and an LDO regulator for such a set-up.

Improvements

This design samples the audio signal at 2kHz, limiting the frequency range of the spectrum display to 1kHz. Would you be happy sacrificing the frequency resolution for higher bandwidth? Just two lines of code determine this. For example, to set the bandwidth to 10kHz, make the following changes:

fft.h
line 15
change 2000 to 20000

main_fft_example.c
line 218:
change 32200 to 3220

Your displayed frequency spectrum will now extend to approximately 10kHz. The microphone amplifier circuit will start attenuating the higher frequencies, but you will be able to observe them – and the previous article will explain how to reference the Texas Instruments application note to change the component values, if you'd like to improve the frequency range.

The microphone amplifier components values can also be tinkered with to increase the gain, depending on your application. Even at fairly high volume this design covers less than a third of the ADC input voltage range, so the gain can be improved. The DC offset can also be nulled by changing the op amp reference voltage DAC, to remove the low frequency artefacts in the output data.

With the inclusion of the LCD there is now a lot of noise visible on the amplified microphone signal, as can be seen in Fig.5. Despite this, the circuit was still able to identify the sound from the guitar strings. This noise could be eradicated by moving the design to a proper PCB, a task we will take up in a later article.

The source code for this project, along with the code to convert bitmap images into header files for including your own pictures in your projects is available for download from the magazine's website.

A video of this month's circuit in action can be viewed here on YouTube: **https://youtu.be/vmtn7JfF36U**

Conclusion

While you could download an application to your phone to do the same thing as this little project, isn't it more fun to build the hardware from scratch at low cost, and potentially integrate it into some other project of your own devising? This is where home DIY electronics projects excel – being able to create exactly what you want, with just the capabilities you want, in the form factor that you want. As a bonus, should it develop a fault, you will have the skills to repair it – because you built it in the first place!

It's interesting to reflect on what we have done over this series; the process we have followed is just what we would have done if we had been tasked to develop a guitar tuner product from scratch. To be fair, there is a lot missing; we haven't covered manufacturing requirements, robustness or CE certification. But from the product firmware development point of view, this approach is how it is done. We have gone from a simple set of requirements to a useful product design.

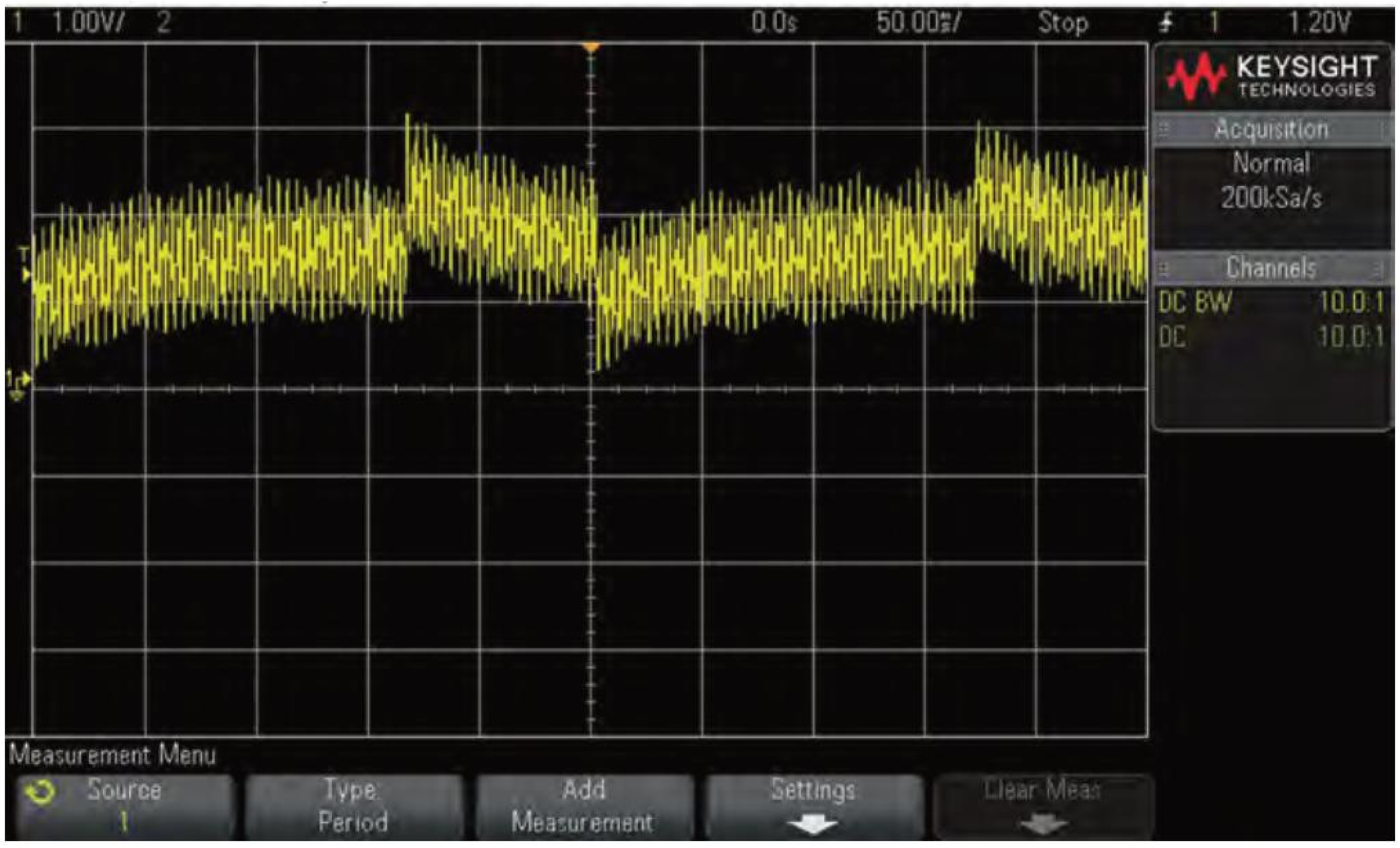

Fig.5. Noise from LCD

Coming soon!

The *PIC 'n Mix* torch is passed back to Mike O'Keefe next month, but Mike Hibbett will return later this year with a new column, titled *Chip Select*. He will start by exploring the further use of DSP algorithms, with the overall theme of useful and educational applications. He will also be looking at practical designs using surface-mount devices, a technology that has become more and more popular with hobbyists.

Reference

1. dsPIC33E/PIC24E Family Reference Manual, ADC

ww1.microchip.com/downloads/en/DeviceDoc/70621c.pdf

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integrate it into some other project of your own devising? This is where home DIY electronics projects excel – being able to create exactly what you want, with just the capabilities you want, in the form factor that you want. As a bonus, should it develop a fault, you will have the skills to repair it – because you built it in the first place!

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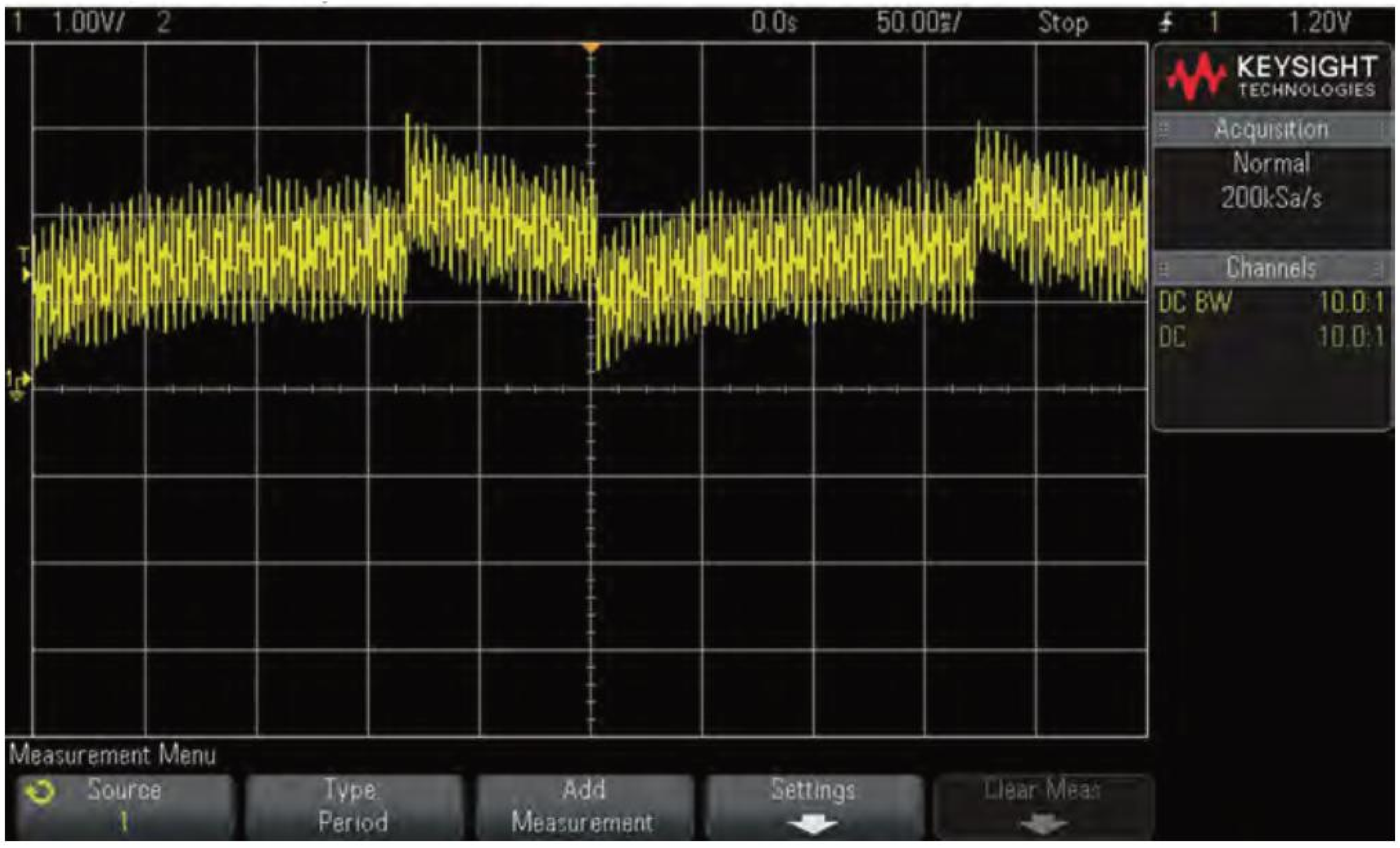

Fig.5. Noise from LCD

Coming soon!

The *PIC 'n Mix* torch is passed back to Mike O'Keefe next month, but Mike Hibbett will return later this year with a new column, titled *Chip Select*. He will start by exploring the further use of DSP algorithms, with the overall theme of useful and educational applications. He will also be looking at practical designs using surface-mount devices, a technology that has become more and more popular with hobbyists.

Reference

1. dsPIC33E/PIC24E Family Reference Manual, ADC

ww1.microchip.com/downloads/en/DeviceDoc/70621c.pdf

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BY IAN BELL

Chopper and auto-zero amplifiers – Part 2

LAST MONTH, we started looking at 'chopper' amplifiers, which are amplifiers designed to overcome the difficulties of working with low-amplitude, low-frequency signals, where 'low-frequency' typically meaning a few hertz and below. Depending on the application, these amplifiers may also be required to handle much higher frequencies, adding to the difficulties of creating suitable circuit designs. The problem with low frequencies is that it is difficult distinguish the wanted signal from the effects of offsets and low-frequency flicker noise. Applications requiring high-performance amplifiers at low frequencies include high-precision temperature measurement, electronic weight scales (and other strain-gauge systems) and medical equipment sensing electrical signals in the body (eg, ECG and EEG).

Offsets and flicker noise

Offsets are DC errors caused by imperfections in the circuit or components. Unfortunately, they are not completely fixed in value for a given amplifier, otherwise a straightforward calibration could permanently subtract the error. Instead, they tend to change with temperature and supply voltage and drift over time as the circuit ages. Thus, offsets behave as low-frequency signals, which cannot easily be separated from the signals of interest in the same frequency range. If the amplitude of the low-frequency signal is small enough to be comparable with the effect of offsets it will be very difficult to accurately amplify the wanted signal with a conventional amplifier.

Another problem for processing low-frequency small-amplitude signals is noise. In this context, 'noise' refers to the random signals generated by all electronic devices, which is fundamentally due to the discrete nature of electricity at the atomic level. Random noise may be classed according to the shape of its spectrum (how its amplitude varies with frequency). White noise has the same power throughout the frequency (f) spectrum, whereas the level of flicker noise (also called $1/f$ noise and pink noise) decreases in proportion to frequency. Standard amplifiers typically exhibit a mixture of pink and white noise, with pink noise dominating at low frequencies. The frequency at which the dominant noise component changes between pink and white noise is called the 'corner frequency' or 'noise corner'. The fact that noises increases at low frequencies in standard amplifiers may mean they are unable to accurately amplify low-frequency signals.

As just discussed, flicker noise and offsets may have a significant impact on circuits processing low-frequency signals. At higher frequencies these problems can be overcome by high-pass filtering, including simple capacitive coupling between stages. At low frequencies, the solution is not simply to design a better conventional amplifier – the unwanted low-frequency signals have to be removed by more sophisticated means, which is where 'chopper' amplifiers come in.

Two techniques

Last month, we explained that there are two fundamentally different approaches to designing amplifiers with very low offset and flicker noise. The first technique, which we discussed in detail last month, is based on amplitude modulation. The modulation process chops the signal by reversing its polarity at the chopping frequency – hence the name 'chopper amplifier'. Modulation is used to prior to amplification to move the wanted signal to a higher frequency band, separating it from the flicker noise and offsets from the amplifier. After amplification, demodulation returns the wanted signal to its original frequency range and shifts the flicker noise and offsets to higher frequencies, which can be removed by filtering. Combining a chopper amplifier with a standard amplifier allows the overall frequency range to be extended in what is called a 'chopper-stabilised amplifier'.

The second technique, which we describe in detail this month, is commonly referred to as 'auto-zeroing', and is based on an error-sampling approach. The fact that switching is used may lead to the term 'chopper' being used for this technique too, although the principle of operation is different from the modulation-based approach described last month. The basic idea is to remove the input signal temporarily, so the amplifier's output is just due to offsets and noise. This error is sampled, typically by storing the error voltage on a capacitor. The amplifier's inputs are reconnected to the signal and the stored error is subtracted from the output to remove it. Like the chopper-stabilised amplifiers discussed last month, auto-zero amplifiers are typically used in the same circuit configurations as operational amplifiers. Like op amps, they typically have very high open-loop gains and are used with negative feedback. In many cases, the auto-zero amplifier ICs have conventional op amp pinouts and could 'drop in' in place of standard op amps. However, to get the best performance from them good board layout is required, which we will discuss later.

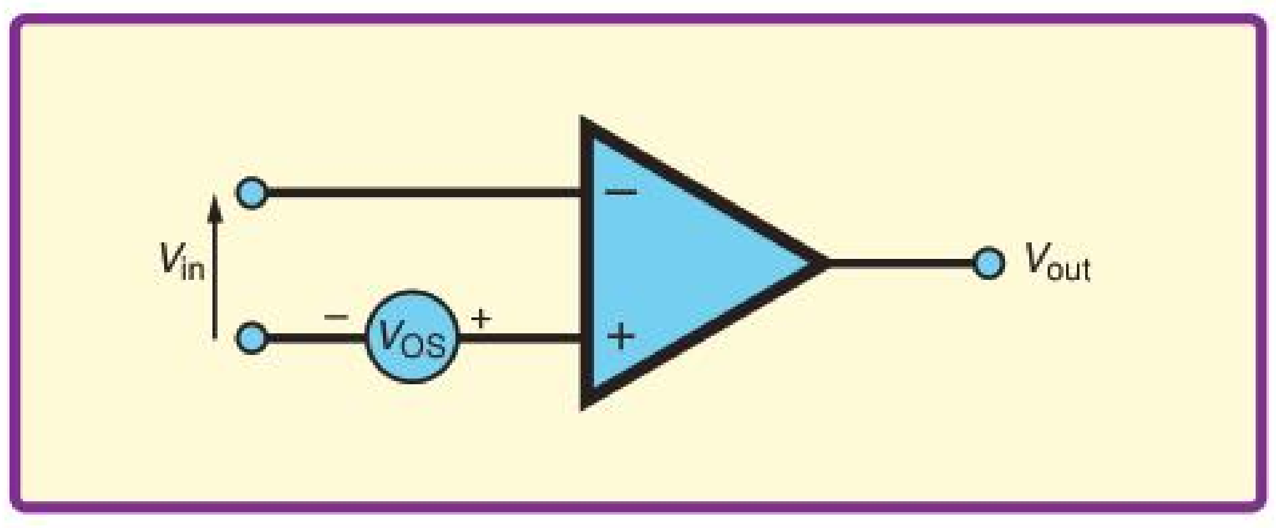

Fig.1. Operational amplifier with input offset voltage.

Analysing offset

Operation amplifier offset can be analysed by assuming that the amplifier itself is ideal, and with the offset created by a voltage source connected to the non-inverting input (see Fig.1). As discussed last month, this voltage is referred to as the input offset voltage (V_{OS}) – it is the voltage required at the input to obtain an output of 0V, and is ideally zero. If an input (V_{in}) is applied to an op amp, its output will depend on both the input signal and the input offset voltage. For the open-loop amplifier circuit in Fig.1, the output will be:

$$V_{out} = AV_{in} + AV_{OS}$$

where A is the open-loop gain of the op amp.

There is more than one circuit that can be used for auto-zeroing an amplifier to reduce the effect of offsets. One approach makes use of an

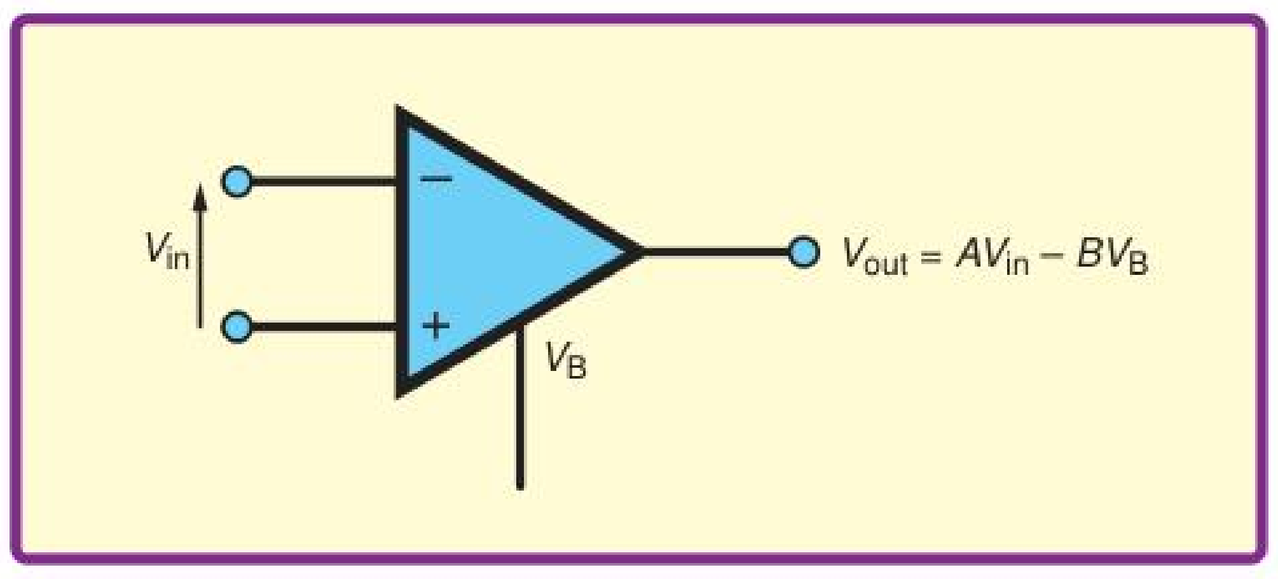

Fig.2. Amplifier with additional input.

amplifier, which is like an op amp in that it has a differential input, but it also has a third input (see Fig.2). The amplifier has a gain of A associated with the differential input and a gain of B associated with the third input. The output voltage (V_{out}) can therefore be written as:

$$V_{out} = AV_{in} - BV_B$$

where V_{in} is the differential input voltage and V_B is the voltage at the third input.

For the amplifier in Fig.2 we can use the same definition of offset voltage as for the basic op amp. The additional input does not change the definition – the offset is still represented by a single voltage source connected to the positive terminal of the differential input (see Fig.3). Including the offset, the output voltage in Fig.2 can be written as:

$$V_{out} = A(V_{in} + V_{OS}) - BV_B$$

Nulling amplifier

The amplifier in Fig.3 can be used to create a circuit which nulls its own offset – the circuit is shown in Fig.4. It comprises the amplifier (A1), a capacitor (C1) to store the nulling voltage, and two switches which periodically reconfigure the circuit to sample the amplifier's output error. The switches are electronic (typically MOSFETs) and are controlled by an oscillator which sets the rate which they switch. When the switch is in position A the amplifier operates normally, the differential input voltage (V_{in}) is amplified and its output is given by:

$$V_{out} = A(V_{in} + V_{OS}) - BV_{C1}$$

However, when the switch is in the B position the amplifier's differential inputs are shorted out, so its differential input is 0V, but of course its offset will still be present. Also, for position B, the output of the amplifier is connected to capacitor C1. In this mode, the output of the amplifier charges C1 to its output voltage, which is given by:

$$V_{out} = V_{C1} = AV_{OS} - BV_{C1}$$

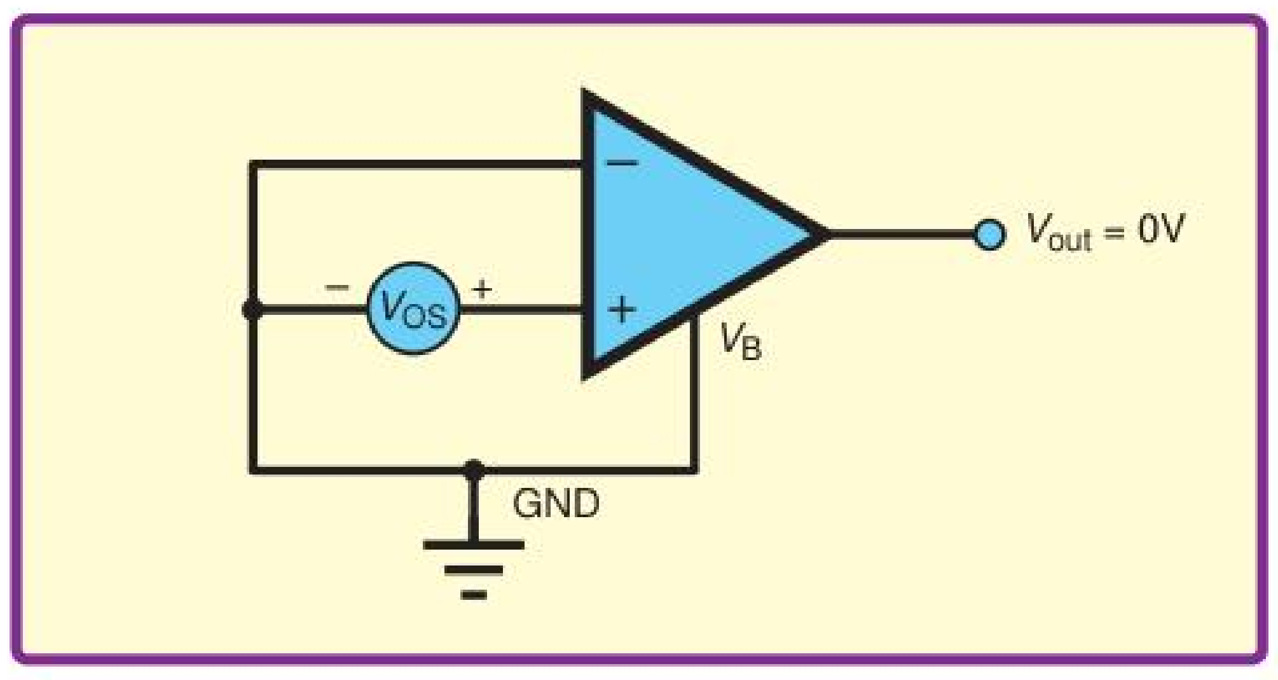

Fig.3. Definition of input offset voltage for amplifier in Fig.2.

Rearranging this equation we get an expression for the voltage on C1, which shows that it depends only on the offset and the amplifier's two gains.

$$V_{C1} = V_{OS}\left(\frac{A}{B+1}\right)$$

Thus, at the end of the period in which the switch is in position B, capacitor C1 is charged to a voltage proportional to the amplifier's offset. This voltage will remain on C1 when the switch is in position A, assuming this time period is not so long that leakage currents cause a change in C1's voltage. We assume that the amplifier's third input has a very high input impedance, and requires low bias current, so C1 can hold its voltage accurately as long as is required.

Offset reduction

Having got the above expression for the voltage stored on C1 when the switch is in the B position, we can substitute this for V_{C1} in the expression for the amplifier's output voltage when the switch is in the A position (normal operation).

$$V_{out} = A(V_{in} + V_{OS}) - BV_{C1}$$

$$V_{out} = A(V_{in} + V_{OS}) - BV_{OS}\left(\frac{A}{B+1}\right)$$

We need a couple of algebraic steps to rearrange the equation so that the terms in V_{in} and V_{OS} are collected together:

$$V_{out} = AV_{in} + AV_{OS} - \left(\frac{AB}{B+1}\right)V_{OS}$$

$$V_{out} = AV_{in} + \left(\frac{A(B+1)}{B+1}\right)V_{OS} - \left(\frac{AB}{B+1}\right)V_{OS}$$

$$V_{out} = AV_{in} + \left(\frac{1}{B+1}\right)AV_{OS}$$

Comparing this with a basic operation amplifier with offset (Fig.1):

$$V_{out} = AV_{in} + AV_{OS}$$

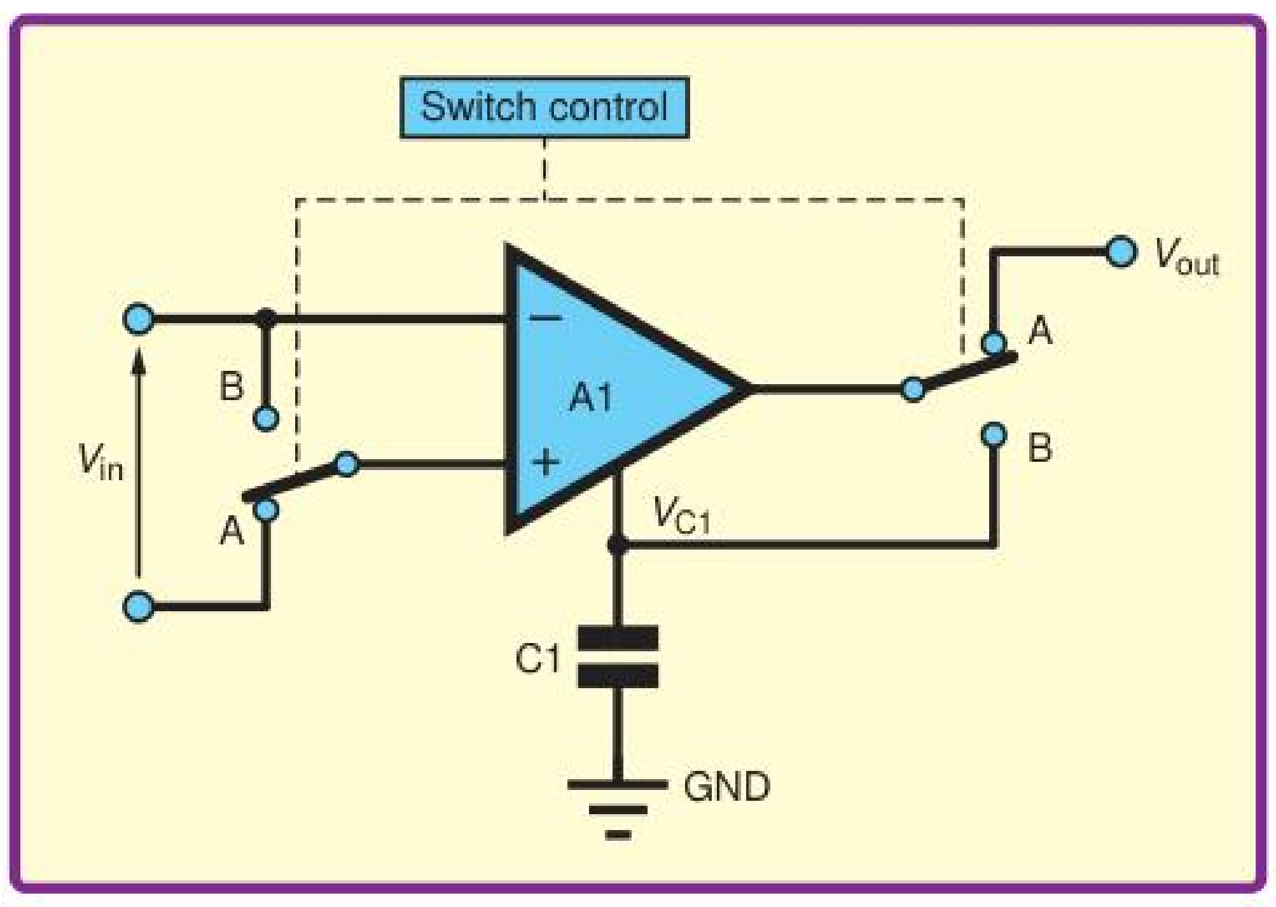

Fig.4. Self-nulling amplifier schematic.

We see that the effect of the offset on the output voltage on the circuit in Fig.4 is reduced by a factor of $B + 1$.

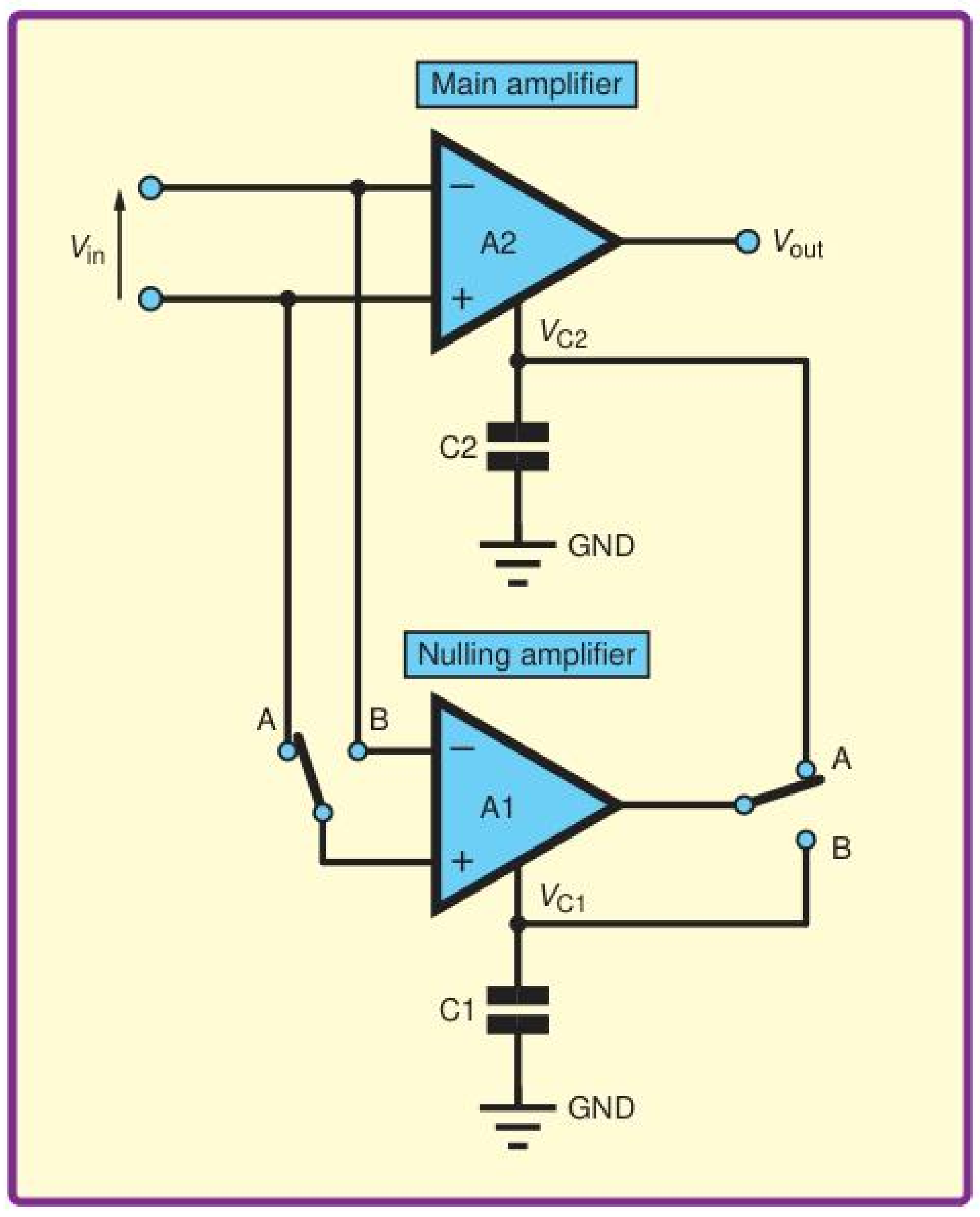

Fig.5. Auto-zeroing amplifier.

Auto-zero amplifier

Given that gain B, like a typical op amp open-loop gain, can be very large, the reduction in offset can be very significant using this approach. The problem is, that while the amplifier is sampling its own error it is not amplifying the input signal and its output is therefore not maintained correctly. This can be overcome by using another amplifier, as shown in Fig.5. In the circuit in Fig.5, A1 is configured as a self-nulling amplifier, exactly as in Fig.4. Its output is used to charge a capacitor (C2) connected to the B input of another very similar three-input amplifier.

The output of the auto-zero amplifier in Fig.5 is given by:

$$V_{out} = A(V_{in} + V_{OS2}) + BV_{C2}$$

Where A is the gain of amplifier A2 with respect to its differential input, B is its gain with respect to the third input, and V_{OS2} is its offset voltage. We will assume that the two amplifiers have very similar design hence equal A and B gain magnitudes (although the sign of the B gains is different). The voltage on C2 (V_{C2}) is the output voltage of the nulling amplifier A1. We have just analysed this circuit (as Fig.4) and can therefore substitute our result for the self-nulling amplifier's output voltage for V_{C2} in the equation above (using V_{OS1} for V_{OS}). We get:

$$V_{out} = A(V_{in} + V_{OS2}) + B\left[AV_{in} + \left(\frac{1}{B+1}\right)AV_{OS1}\right]$$

Multiplying out:

$$V_{out} = AV_{in} + AV_{OS2} + BAV_{in} + \left(\frac{B}{B+1}\right)AV_{OS1}$$

Collecting the V_{in} terms together:

$$V_{out} = (1+B)AV_{in} + AV_{OS2} + \left(\frac{B}{B+1}\right)AV_{OS1}$$

We note that the gain B is very large, so $B/(B + 1)$ is approximately equal to 1 and $(1 + B)$ is approximately equal to B. This allows us to simplify the equation to:

$$V_{out} = ABV_{in} + A(V_{OS2} + V_{OS1})$$

We can see that the input voltage is amplified by a gain which is the product of the A and B gains – so the auto-zero amplifier will have a high open-loop gain. It is useful to again try to compare this with a basic op amp with offset (Fig.1, with gain A) for which we have:

$$V_{\text{out}} = AV_{\text{in}} + AV_{\text{OS}} = A(V_{\text{in}} + V_{\text{OS}})$$

Rearranging the auto-zero amplifier equation into a similar form (with gain AB) we get:

$$V_{out} = AB\left[V_{in} + \frac{(V_{OS2} + V_{OS1})}{B}\right]$$

For a basic op amp with gain AB we would have $V_{\text{out}} = AB(V_{\text{in}} + V_{\text{OS}})$, so in comparison, the effective offset of the auto-zero amplifier has been reduced by a factor of B (or $B/2$ if you consider the sum of the two offsets to double the effective offset). Given that the value of B may be tens of thousands or more this is a very significant reduction in the offset.

The circuit in Fig.5 does not suffer from the problem identified for Fig.4, in that the input signal is continuously amplified by A2. The switching process applied to A1 periodically updates the offset correction applied to A2, enabling it to correct a shifting and drifting offset.

So far we have discussed the circuit in terms of offset, but not flicker noise. The troublesome flicker noise will be a much lower frequency than the switching applied to the auto-zero amplifier and so it will appear as an error in the amplifier's output, which, like the offset, is more or less fixed during one auto-zero switching cycle. Thus the flicker noise will be reduced in the auto-zero amplifier's output in the same way as the offset. The reduction of flicker noise is more effective at lower frequencies.

Problems

The sampling clock used in auto-zero amplifiers can be a source of problems in that the auto-zeroing frequency (clock frequency) and its harmonics may feed through into the output signal of the amplifier. The higher the closed-loop gain of the circuit in which the auto-zero amplifier is used, the higher the amplitude of the clock feedthrough. If the signal frequencies are lower than the clock frequency, then cutting the gain of the amplifier at higher frequencies can reduce the problem. Typically, this is achieved by connecting a suitable capacitor across the feedback resistor. This technique cannot be used if a wideband amplifier is required.

We saw last month how modulation shifted signals within the frequency spectrum. Similarly, in the auto-zero amplifier, for a signal frequency (f_S), variations in the effective circuit gain at the auto-zero sampling frequency (f_Z) generate signals at frequencies of the sum and difference of the two frequencies: $f_Z + f_S$ and $f_Z - f_S$. If f_{SM} is the maximum signal frequency and f_{SM} is greater than $f_Z/2$ then $f_Z - f_{SM}$ will be within the range of signal frequencies. Adding content to a signal at frequencies different from the original signal will change the shape of the waveform – that is the waveform will be distorted. Distortion relating from the interaction of multiple frequencies is called intermodulation distortion and is a problem in auto-zeroing amplifiers.

Another possible problem with auto-zero amplifiers is their response to overload conditions, which occurs when very large input signals push the output into saturation at one of the supply rails. Under these conditions the circuit is no longer a linear amplifier and is therefore unable to find the correct nulling voltage to compensate for offsets. Thus, after an overload a chopper amplifier may take some time to recover to full performance. Similarly, at power-up, it will take a while for an auto-zero amplifier to correctly settle its output.

Auto-zero ICs

There are a number of commercial ICs with circuitry similar to that described in this article. They feature lower offsets and offset drift than can be achieved with conventional op amps. The TLC2654 from Texas Instruments has an input offset of 10μV and an offset drift of 0.05μV/°C. Its auto-zero frequency is 10kHz, meaning that intermodulation errors can be avoided in circuits with bandwidths below 5kHz. The TLC2652, also from Texas Instruments, has higher precision than the TLC2654, but lower bandwidth. It has a 1μV offset voltage and an offset drift with temperature of 0.003μV/°C. The auto-zero frequency is 450Hz.

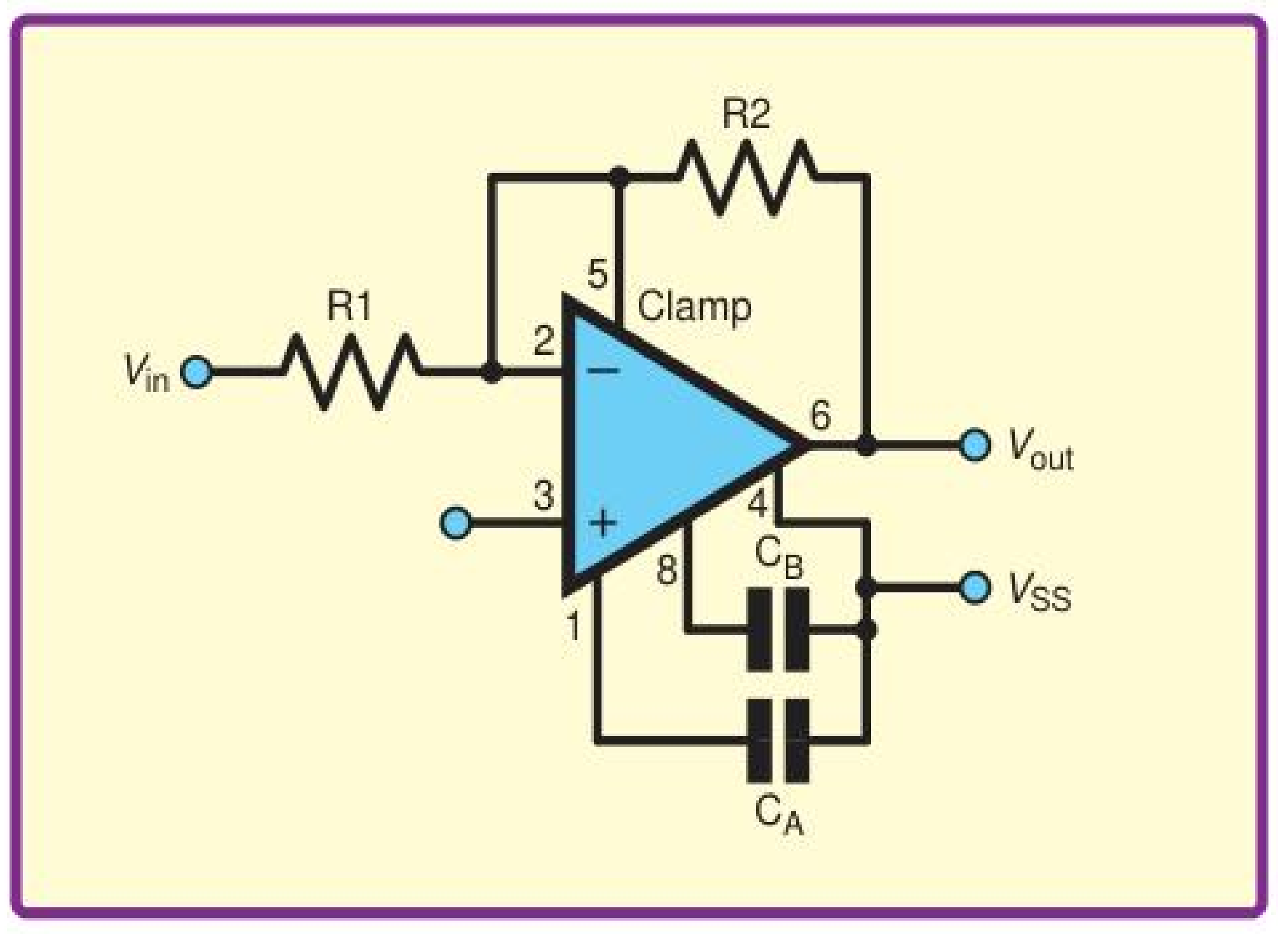

Fig.6. TLC2654/TLC2652-based amplifier showing external sampling capacitors and clamp connection (based on Texas Instruments datasheet).

The TLC2654 and TLC2652 require external capacitors (for C1 and C2 in Fig.5) so are not exact drop-in replacements for standard op amps, unlike some other auto-zero amplifier ICs. These devices also have a CLAMP pin, which provides a means for the internal circuitry to detect overload conditions and hence prevent the amplifier from becoming heavily saturated. This in turn speeds up recovery once the overload condition is removed.

If clamping is required, the CLAMP pin is connected to the inverting input IN– (in parallel with the closed-loop feedback resistor – see Fig.6). If connected, the clamp is automatically activated when the output is approximately 1V from either supply rail. When activated, the clamp reduces the gain of the amplifier and the output is prevented from going into saturation. Since the output must source or sink current through the clamp circuitry the maximum output voltage swing is slightly reduced when the clamp is used. The TC7650 from Microchip is an auto-zero amplifier similar to the TLC2654/TLC2652.

The AD8551/AD8552/AD8554 from Analogue Devices are single, dual and quad auto-zeroing amplifiers respectively. The auto-zero switching frequency is fixed at 4kHz. They have a 1μV offset voltage and an offset drift with temperature of 0.005μV/°C. These devices do not require external capacitors and can be used in conventional op amp circuits with a unity gain bandwidth up to 1.5MHz.

The AD8571/AD8572/AD8574, also from Analogue Devices, are a similar set of devices to the AD8551. A key feature of these devices is that the auto-zero clock frequency continuously varies in a random manner (or more accurately on a pseudorandom basis) – an approach known as 'spread spectrum clocking'. The clock frequency has a uniform distribution from 2kHz to 4kHz. The effect of this is to spread out the effect of clock feedthrough and intermodulation distortion over a wide range of frequencies, so that unwanted signals behave like noise rather than intrusive fixed frequencies or distortion.

We have mentioned some, but not all the ICs which use the auto-zeroing technique described here. Others include the LMV2011 from Texas Instruments and the TC913A/TC913B from Microchip. Other IC use different but related approaches; for example, the OPA335 from Texas Instruments uses two nulling amplifiers, which operate in an alternating mode. While the first nulling amplifier nulls its own offset the second is correcting the main amplifier's offset and vice versa. The alternating operation of the nulling amplifiers minimises output voltage ripple and intermodulation distortion.

Layout considerations

To get the full benefit of the high-precision capabilities of chopper stabilised and auto-zeroing amplifiers, good circuit board layout is required. Problems are caused by leakage across the PCB, so thorough cleaning and drying after construction is important. A useful technique is to include an input 'guard' in the PCB layout. A guard is a PCB track in a ring surrounding the input terminals, which absorbs leakage currents. The ring connects to a low-impedance point, ideally at the same common-mode voltage as the inputs. The concept of the PCB guard ring layout is shown in Fig.7, based on one of the amplifiers in the AD8552; the actual layout for a given application will depend on the IC package used.

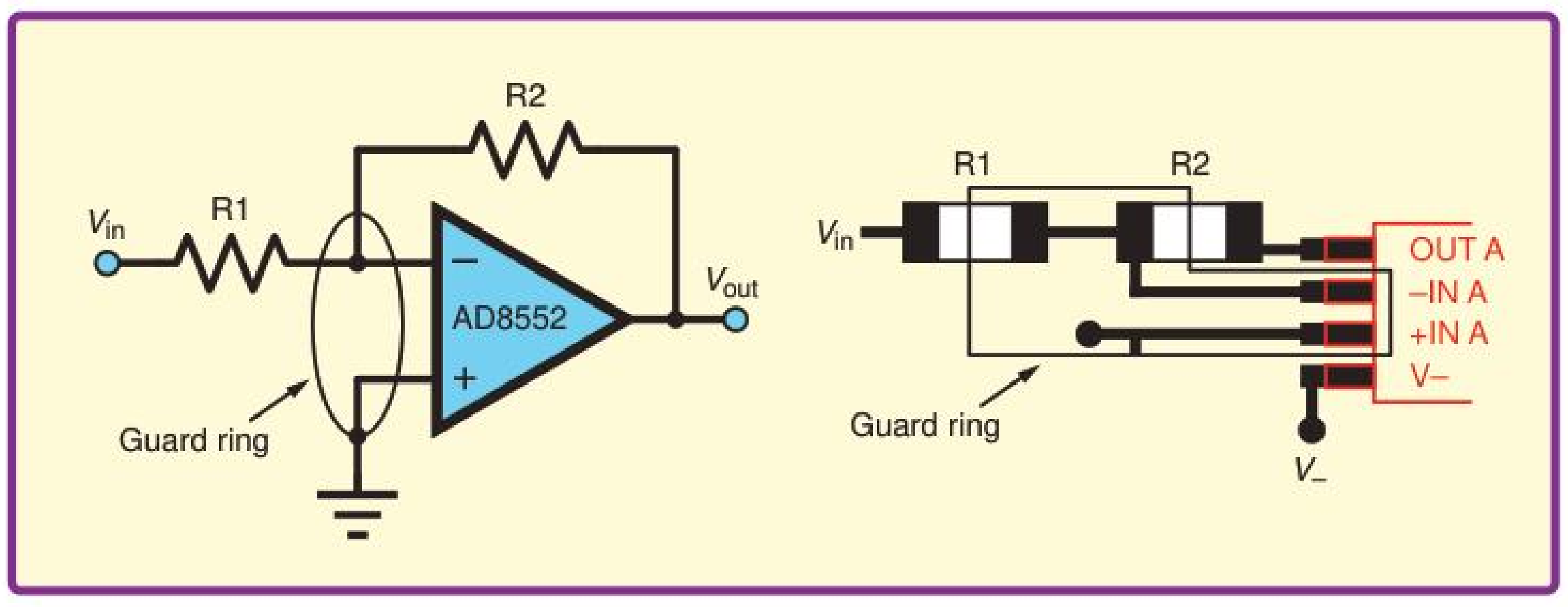

Fig.7. Schematic of inverting amplifier and PCB layout with guard ring for one of the auto-zeroing amplifiers in the AS8552 surface mount SOIC package (based on layout from Analogue Devices data sheet).

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Pi Wars

Pi Wars is a non-destructive, challenge-based robotics competition in which Raspberry-Pi-controlled robots compete in numerous non-destructive challenges to earn points. This year's competition took place on 21/22 April 2018 at the University of Cambridge Computer Laboratory.

It's a two-day event, with schools and kids' clubs competing on the Saturday. Families, groups of hobbyists and solo roboteers take part on the Sunday. Teams from all over the world compete – this year, there were teams from the US, Turkey, Malaysia and Hong Kong, as well as local competitors from England, Scotland and Wales.

There are three challenges that have to be done autonomously – once the robot is set off it can't be touched or controlled again:

- *Straight-line speed test* (don't hit the sides!)
- *Minimal Maze* (very basic for humans – hard for a robot)
- *Somewhere Over the Rainbow* (Robots are placed at the centre of a square arena. At each corner there's a coloured ball. The robots must visit each ball once. They can do this in any order, but get more points if they go in a predetermined order.)

Then there are four challenges that are done using remote control:

- *Obstacle course*
- *Slightly Deranged Golf* (like crazy golf)
- *Duck Shoot* (requires a method to knock things over at a distance)
- *Pi Noon* (robot vs robot challenge, where you have three balloons and a pin attached to your robot and you need to burst your opponents balloons before they get yours.)

There are also points for blogging about the build, artistic merit and technical merit. I judged the technical merit section.

All the teams adhere to the same set of rules, but some challenges have more complex options that you can opt in to (and thereby gain further points). This is great, as it means everyone does the same contests, has the opportunity to get a sense of achievement but also provides a greater challenge for the more advanced teams. Sometimes the advanced competitors overstretch themselves, try something very new or novel and fail completely, whereas a beginner with a slow-and-steady style often plods on and completes the challenge to win. One team (Mark Mellors and his Pi-radigm robot **http://hackhitchin.org.uk/pi-wars-2018/**) attempted to do *every* challenge autonomously. Although this apparently worked perfectly in the home and makerspace environment, he had a lot of technical issues on the day. Nevertheless, he certainly inspired everyone.

Last year, I judged technical merit and made a comment that many of the robots' wiring was a rats nest. This year, that comment was taken to heart, and most teams had either neatly taped, colour coordinated wiring or better still, added connectors. Some teams even mentioned that a lot of their reliability issues disappeared after doing this!

Have a go!

One of the great things about the challenges is everyone can have a go. If you are brand new to Raspberry Pi and making, you can use a kit (such as Camjam Edukit 3 (**http://camjam.me/?page_id=1035**), the Piborg Yetiborg (**www.piborg.org/robots/yetiborg-v2**) and the Coretec Robotics Tiny 4WD robot kit (**http://bit.ly/2rKeR5L**). From there, you 'just' do the programming yourself, and use a cardboard box as the chasis. Then you can progress to making your own chassis – 3D print, laser cut, bent metal, wood or adapted teapots (yes really). Some teams even made their own PCBs.

Everyone gained ideas from everyone else. Whether it was battery choice (alkaline batteries don't last long enough), a cunning Lego attachment to shoot the ducks or someone's code posted on Github – the camaraderie is amazing. There were a lot of sponsors for this event – which meant that every team that entered went home with a prize. They all deserved it. The amount of time and thought that went into each and every robot was amazing.

Next year

The organisers are currently discussing whether to hold a Pi Wars event in 2019. There is a mailing list for notifications and updates: **https://piwars.org/mailing-list**

Pi Wars and Cambridge Raspberry Jam

Pi Wars is an event organised by the Cambridge Raspberry Jam (**camjam.me**) team of Michael Horne and Tim Richardson. They are volunteers who fully support Raspberry Pi's aim of improving the computing and making skills of both children and adults alike by organising events such as CamJam and Pi Wars.

You can watch the fun at: **http://bit.ly/2jYLngX**

Raspberry Pi background

In case you've been living under a silicon stone, a little about the Raspberry Pi (**www.raspberrypi.org**). It is a credit card-sized computer originally designed for education, inspired by the 1981 BBC Micro. The goal was to create a low-cost device that would improve programming skills and hardware understanding at the pre-university level. Thanks to its small size and accessible price, however, makers, electronics enthusiasts and even industry quickly adopted it. Over 19 million have now been sold. About a third are used in education, a third for enthusiasts and a third are used commercially in industry.

The Raspberry Pi Foundation is a charity that aims to put the power of computing into the hands of people all over the world. One way they do this is by providing small, low-cost Raspberry Pi computers that people use to learn and have fun.

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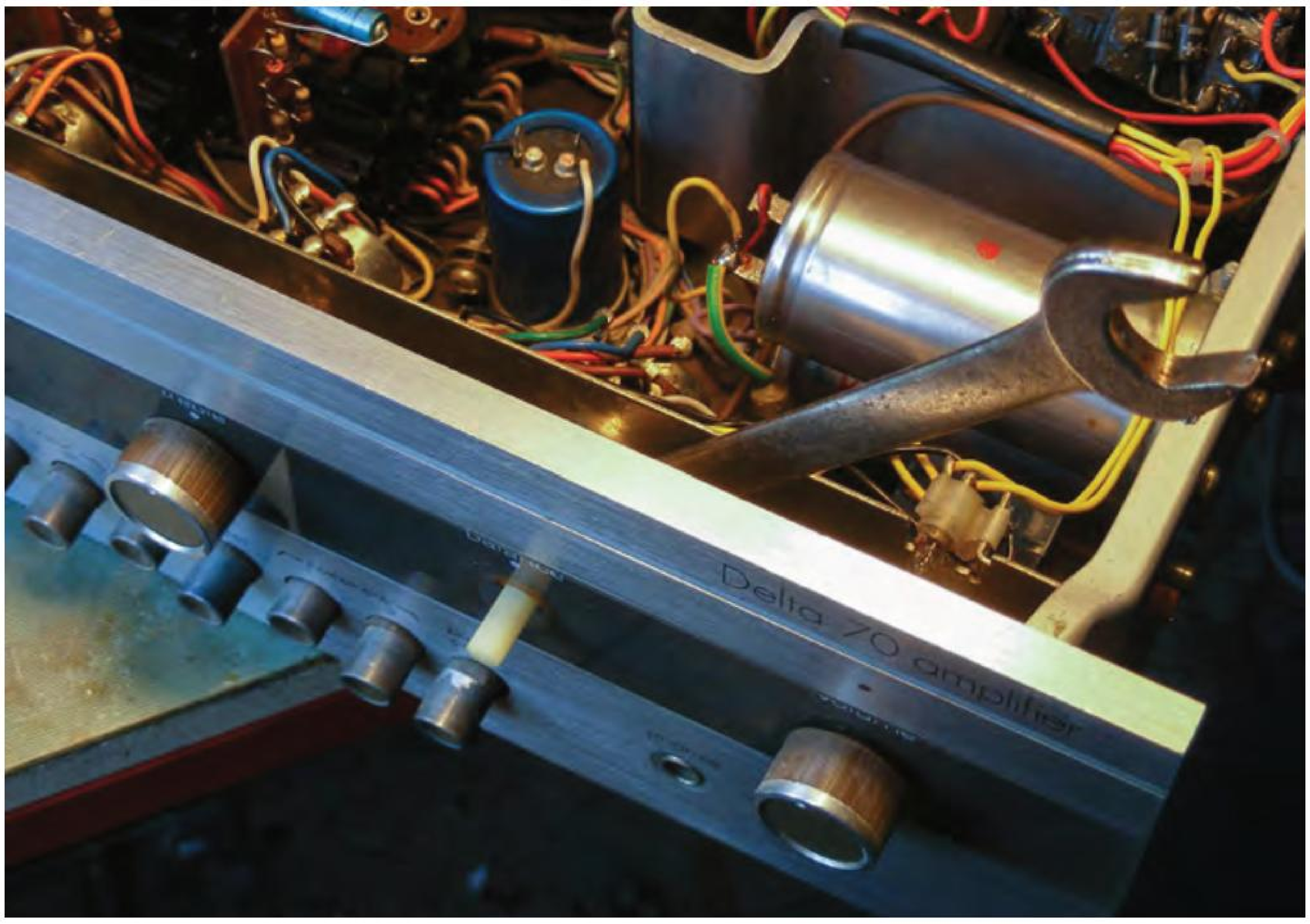

Fig.18. Old equipment, such as this Leak amplifier, can often be easily disassembled. To change a potentiometer in this amplifier just meant undoing the nut with a spanner.

Last month, we started to look at how and why electronic component and circuits become life expired. We conclude this month with some more observations on electronic equipment's route to the skip!

Reparability

A constant conflict is maintainability versus ease of manufacture. Obviously, it is much easier (and cheaper) to make a piece of equipment on one PCB. However, this often makes it hard to replace parts. If a unit is modular with hard-wired panel controls like the Leak Delta 70 amplifier in Fig.18, then it is much quicker to repair. Plug-in PCBs also make the Leak simple to fix (Fig.19) – in this example, it is much more straightforward to replace a hard-wired pot (Fig.20) than its PCB-mounted equivalent, which often requires complete disassembly. However, the associated increase in connections and complexity required in producing repairable equipment means it is more likely to go wrong and often costs more to build. Total resource availability – including the amount of time available to perform its task – is the key to successful commercial equipment, and good maintainability is the main factor in achieving this.

Dirt build-up

Often, equipment fails due to dust and dirt build-up, especially in high voltage devices, such as CRT-based displays, electrostatic speakers and condenser microphones – the high voltages electrostatically attract airborne dust. Cleaning with distilled water and isopropyl alcohol usually does the clean-up trick. In general, cleaning is the only routine maintenance electronic equipment needs. It

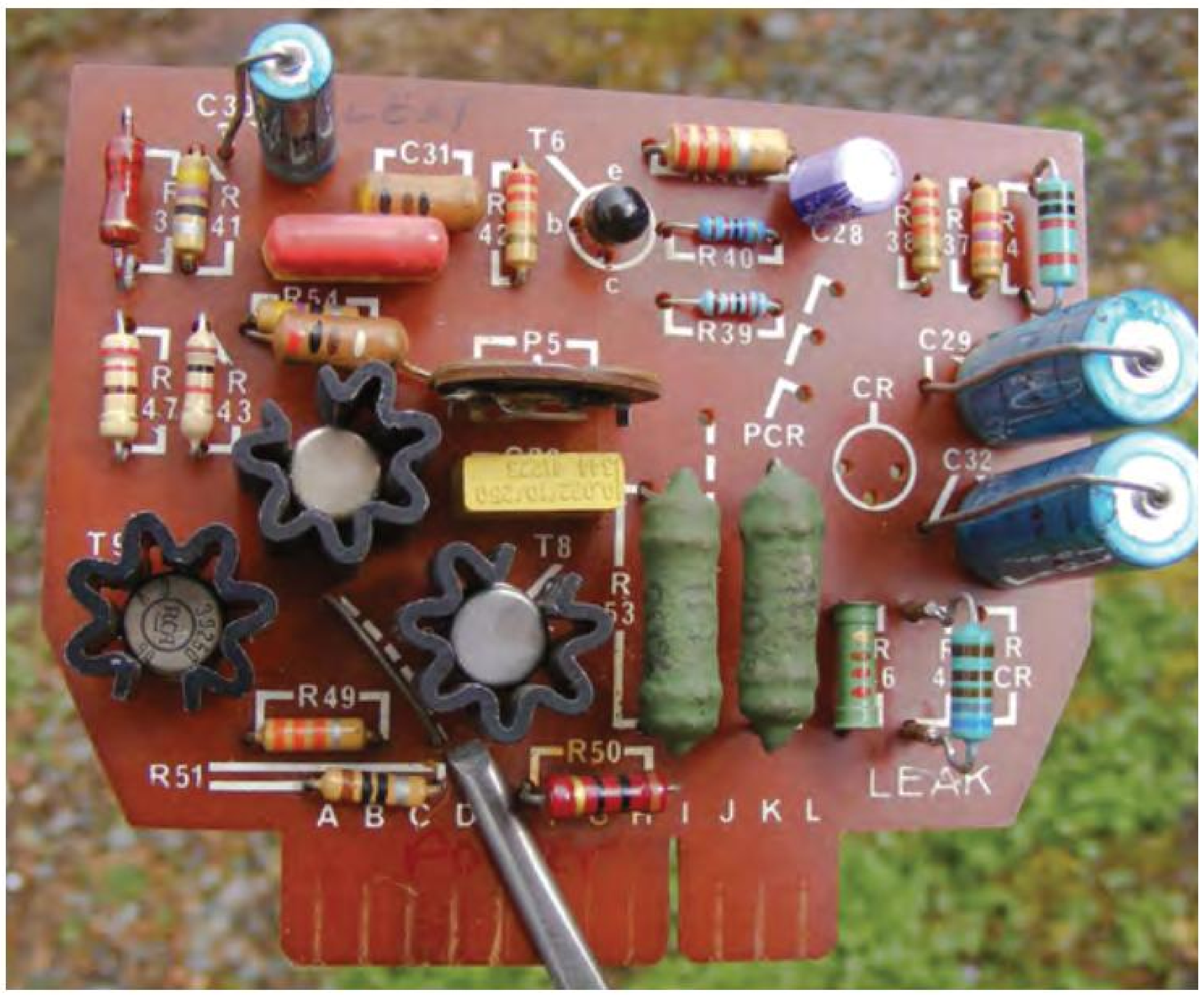

Fig.19. This Leak amplifier was designed for easy maintainability by using plug-in PCBs, unlike most modern audio equipment. However, there is a cost to pay for this approach – the labour in building such an amp today would push it into the £400.00 bracket.

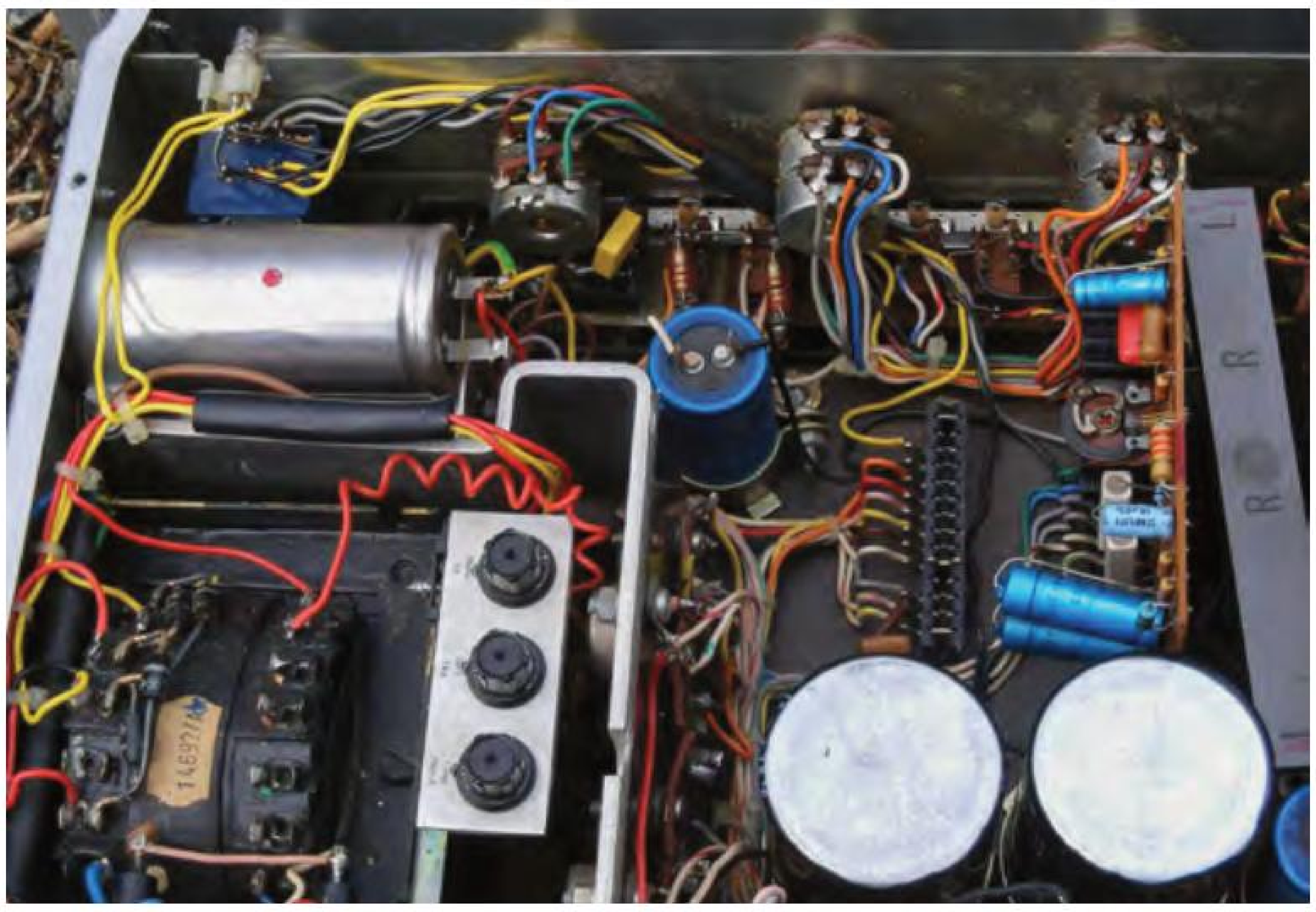

Fig.20. The amount of hand wiring in the Leak amplifier is clearly apparent. It makes jobs like replacing pots a dream compared to changing PCB-mounted components.

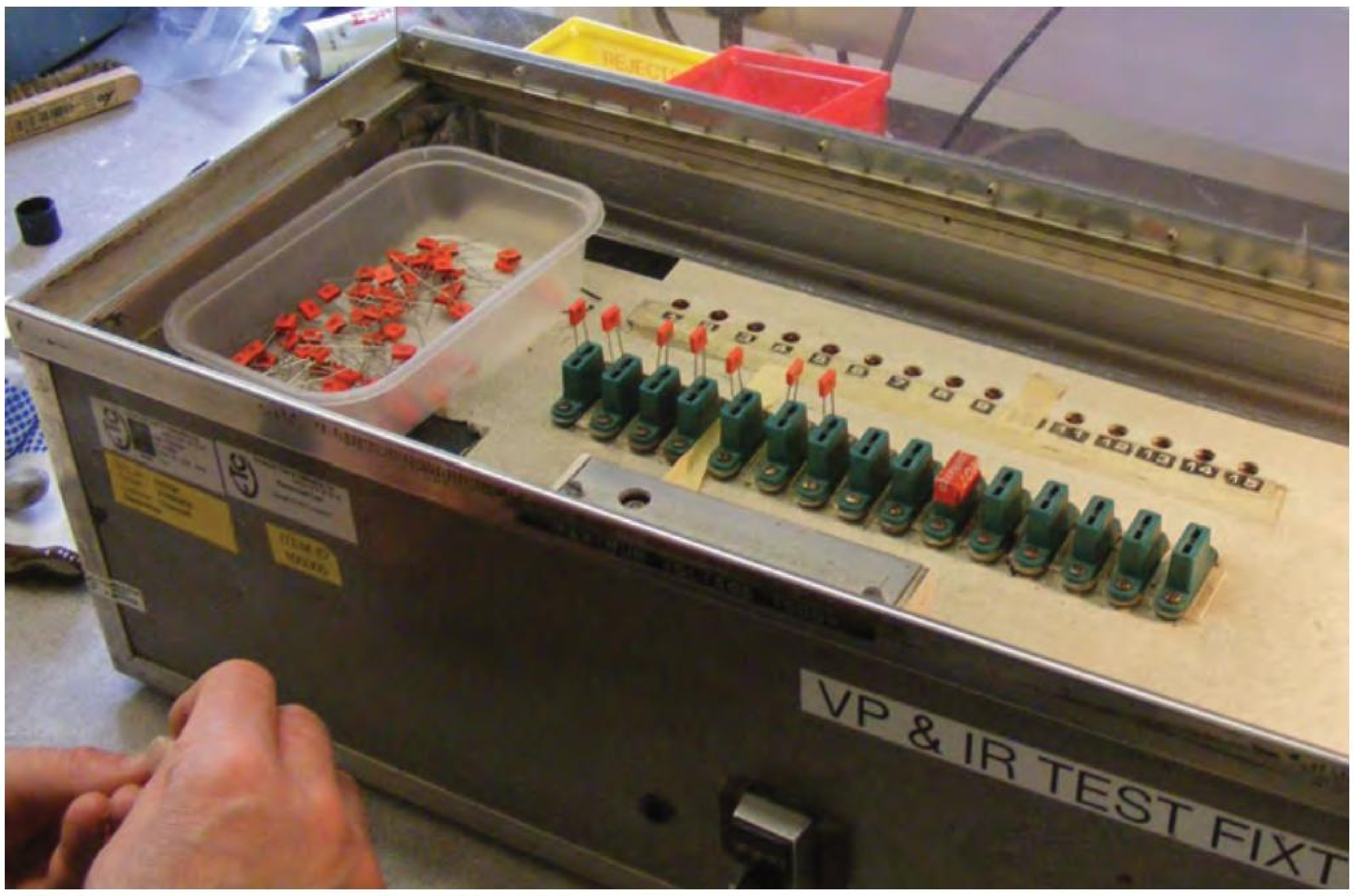

Fig.21. In industry, unique test jigs can be a vital part of the intellectual property on which production depends. This voltage proof and insulation resistance tester for silvered-mica capacitor production at Charcroft Electronics has been going since 1982.

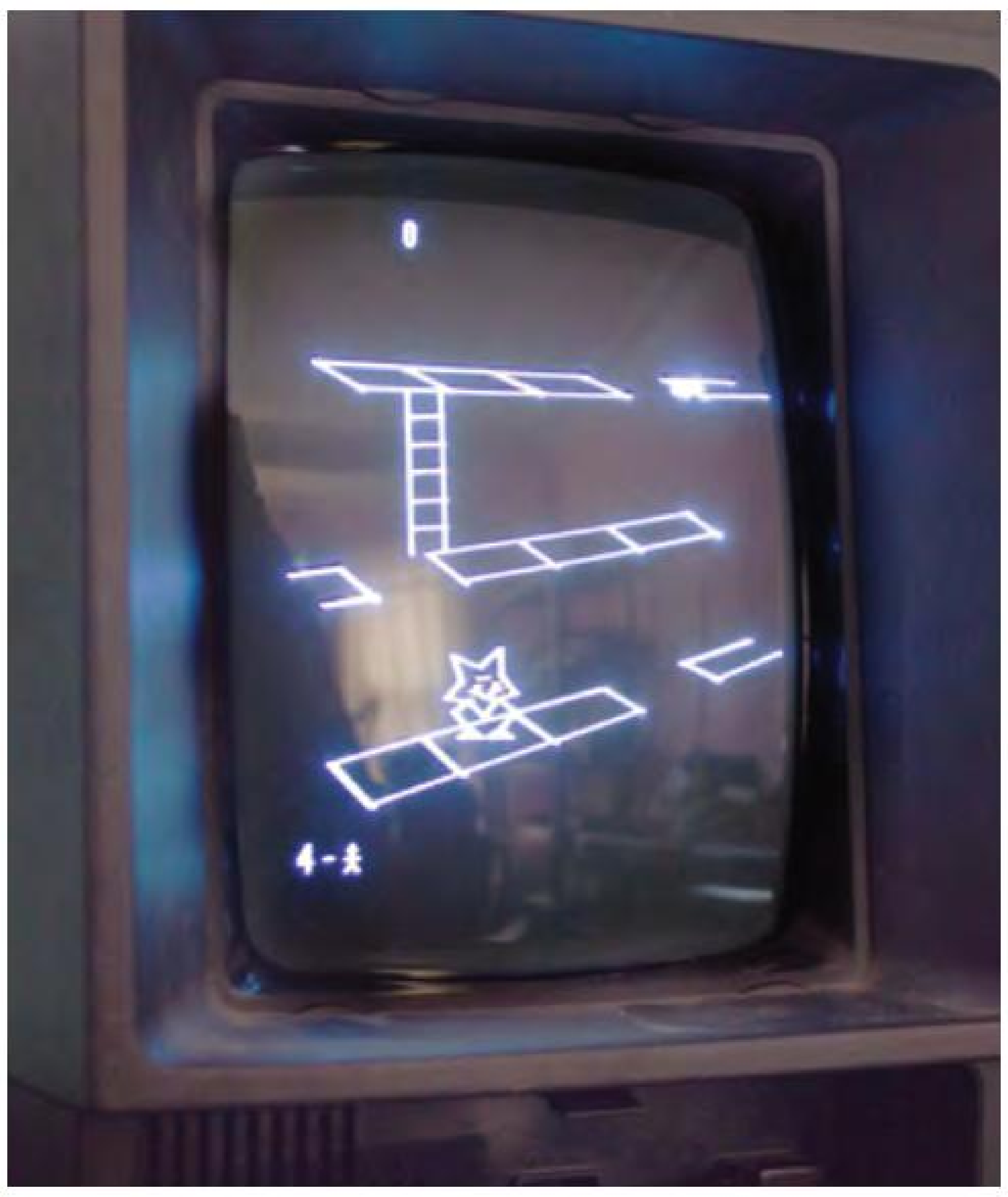

Fig.22. Some electronic items are so weird and unique they just have to be fixed, and it's worth finding solutions. This Vectrex vector-graphics-based games console is a classic.

has been shown periodic disassembly actually decreases reliability – in other words, equipment is more likely to fail after servicing!

Analogue is forever

For a while, when everything digital was the 'latest and coolest thing', analogue somehow became an insult, but as far as electronic equipment is concerned it is a major factor in assuring long life, especially if it is hand assembled and discrete.

Some equipment has to last 'forever', such as dedicated production equipment and jigs in factories. I often help out at the Charcroft capacitor production facility where some of the equipment dates back to the 1970s and must be kept operating (see Fig.21). Recording studios and musicians have to keep equipment working if it has a unique sound unobtainable with modern gear. I have a paper frequency response plotter called a Nutrix Audiograph that enables me to do things no software can do yet.

Obsolete parts

Often, equipment is declared life-expired when the supply of spare parts dries up. This is one problem area that has actually got better recently, thanks to the Internet. There always seems to be someone somewhere online who has the part one needs. I had a Vectrex vector graphics gaming console (Fig.22) that needed an obscure GI chip. The fault was identified from a forum and someone on there also had some chips for £7. Many companies sell legacy parts. Charcroft have to do this for their military customers because a fleet of aircraft and their associated avionics may need to be in service for 35 years.

Proprietary software and encryption

This is my personal digital nightmare – lost encryption keys, passwords, upgraded operating system code incompatibility. I have fully populated *EPE Theremin Midi Box* boards from the late 1990s that need an obsolete microcontroller chip with uncrackable encryption on the code. These boards were stillborn; I grieve having to put them in the bin. It's a tragedy constantly played out; perfectly functioning hardware rendered useless by one obscure digital weak link. I have even heard of multimillion pound locomotives stuck in sidings for months because of this problem.

Diagrams and schematics

If you want to avoid the life expiration of a piece of equipment then a circuit diagram can be vital. However, circuit diagram availability online fluctuates. All too often, diagrams are deliberately withheld on an intellectual property rights basis and this has been getting much worse recently. No diagram slows down diagnosis and can leave equipment faulty for weeks on end.

PCB damage

Old gear that was hardwired on a metal chassis, such as the famous Bush TR82 radio, shown in Fig.23, can be 'endlessly' repaired. PCBs are more fragile, especially the old brown paxolin types. Often, broken pads on older designs can be repaired with bits of tinned copper wire (Fig.24). Surface-mount boards used to be considered irreparable (Fig.25) but there are now stick-on pads

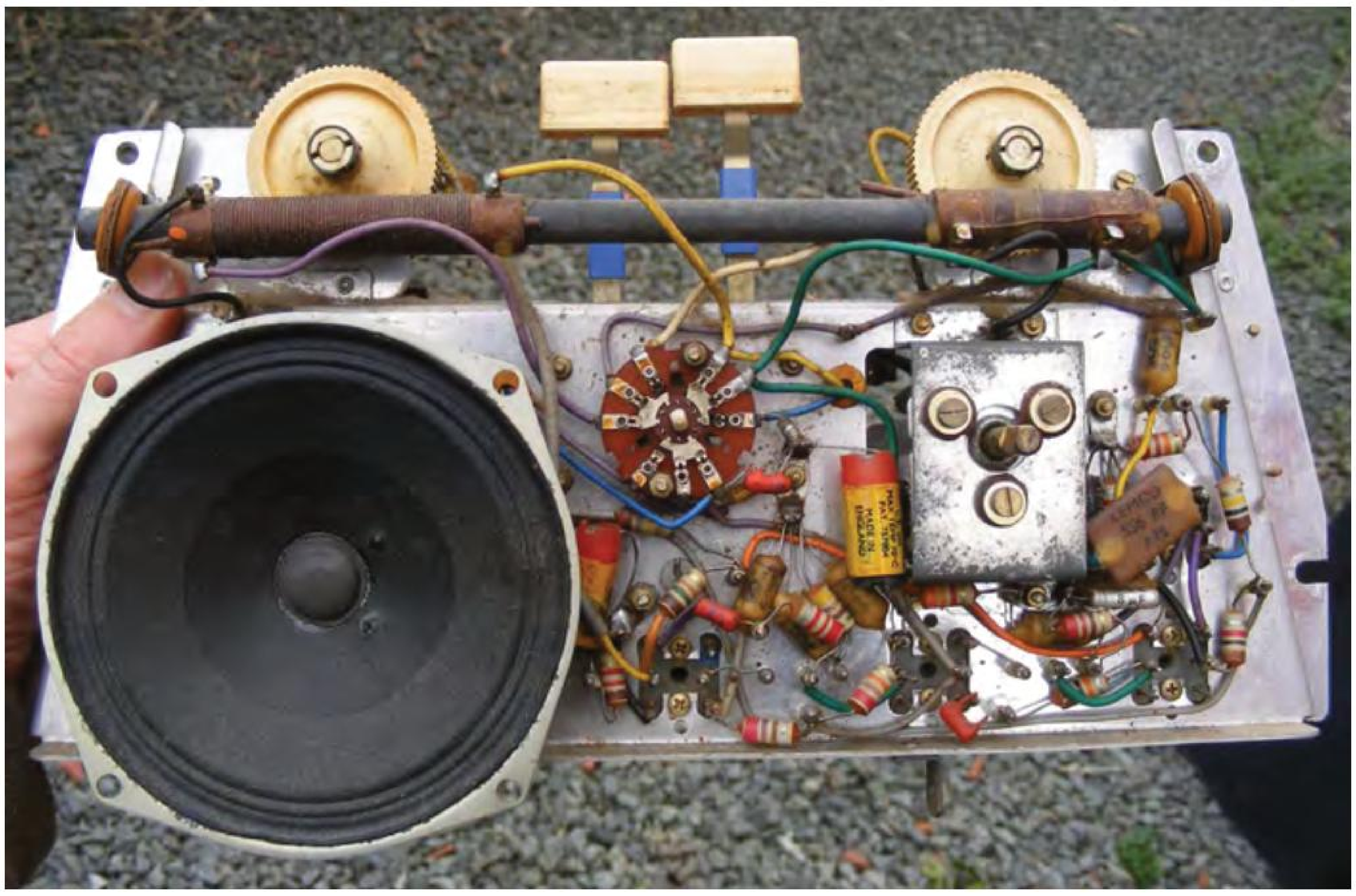

Fig.23. This 1963 Bush TR82 transistor radio chassis is totally hard-wired using no PCB, which means it can be repaired forever.

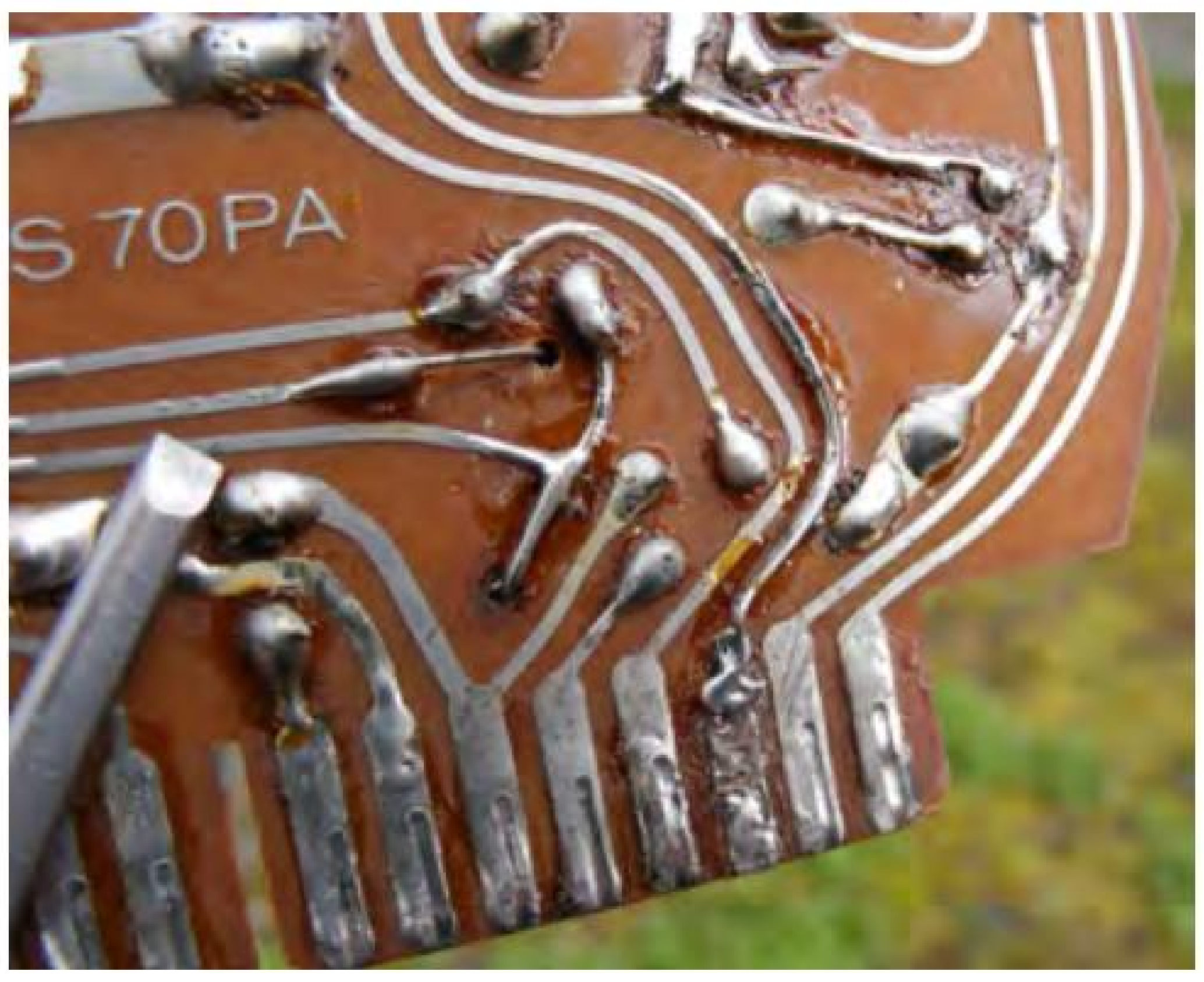

Fig.24. PCB damage after component replacement by heavy-handed desoldering can usually be fixed with wire links.

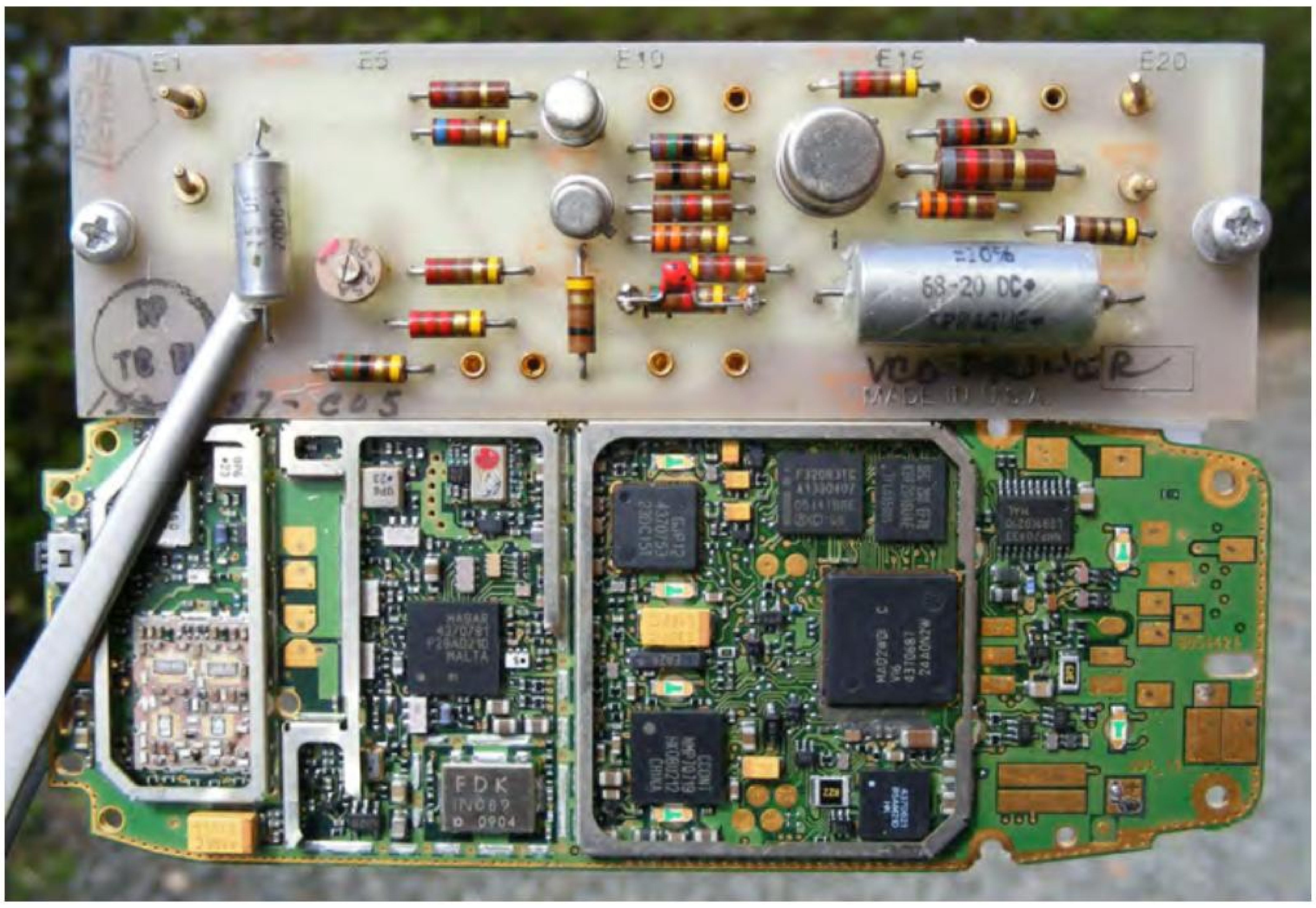

Fig.25. A comparison between a classic always-repairable discrete PCB and the high-density surface-mount technology of a mobile phone. If the SMT board gets a drop of water on it resulting in tracks dissolving that is the end. I do remember the shoe-box sized Motorola mobiles of the early eighties that used traditional repairable PCBs.

and tracks on frames available for surface-mount boards from companies like Intertronics. This is a boon when you have to deal with pulled-off HDMI and mini-USB connectors. However, burnt out areas on multilayer surface-mount boards are usually terminal. If the equipment is rare and/or expensive, such as the Naim amplifier shown in Fig.26, then it is worth investing a few hours to cut out the burnt area (Fig.27) and glue in some new fibreglass with epoxy resin (Fig.28). Holes can then be drilled and replacement components hard-wired in.

Corrosion

A constant enemy of electronics is corrosion, especially around battery connections. Electrolytic corrosion due to current flow is worse, often arising from water, capacitor/battery electrolyte (Fig.29) or acidic drinks.

Inductors (Fig.30) are normally the most reliable components except for the ones that use fine wire which often corrodes, resulting in an open circuit.

I often get rusty Colorsound guitar effects pedals in for repair (Fig.31). I suspect the damage-causing liquid is spilt beer. I usually just change the pots and the pedal's good for another 30 years.

Loss of information

Sometimes, equipment becomes irreparable because the critical mass of readily available knowledge needed to keep it going has disappeared. Many businesses are taken over, founder members of staff are let go (and eventually die) and labs cleared. With time, irreplaceable tacit knowledge is lost. If a company cares enough about its historical products then it may make a real effort to archive material – such as with Quad and Kef – but all too often one is met with the response 'we don't support that anymore'.

Eye of the beholder

There is no clear-cut definition of life expiry with any machine. It is a matter of cost-benefit analysis, and fashion. A strict business-case for repair and retention is not always required. The home electronics buff can repair things just for posterity's sake, even if it's just to savour the phenolic aroma of granddad's old valve radiogram. Restoration

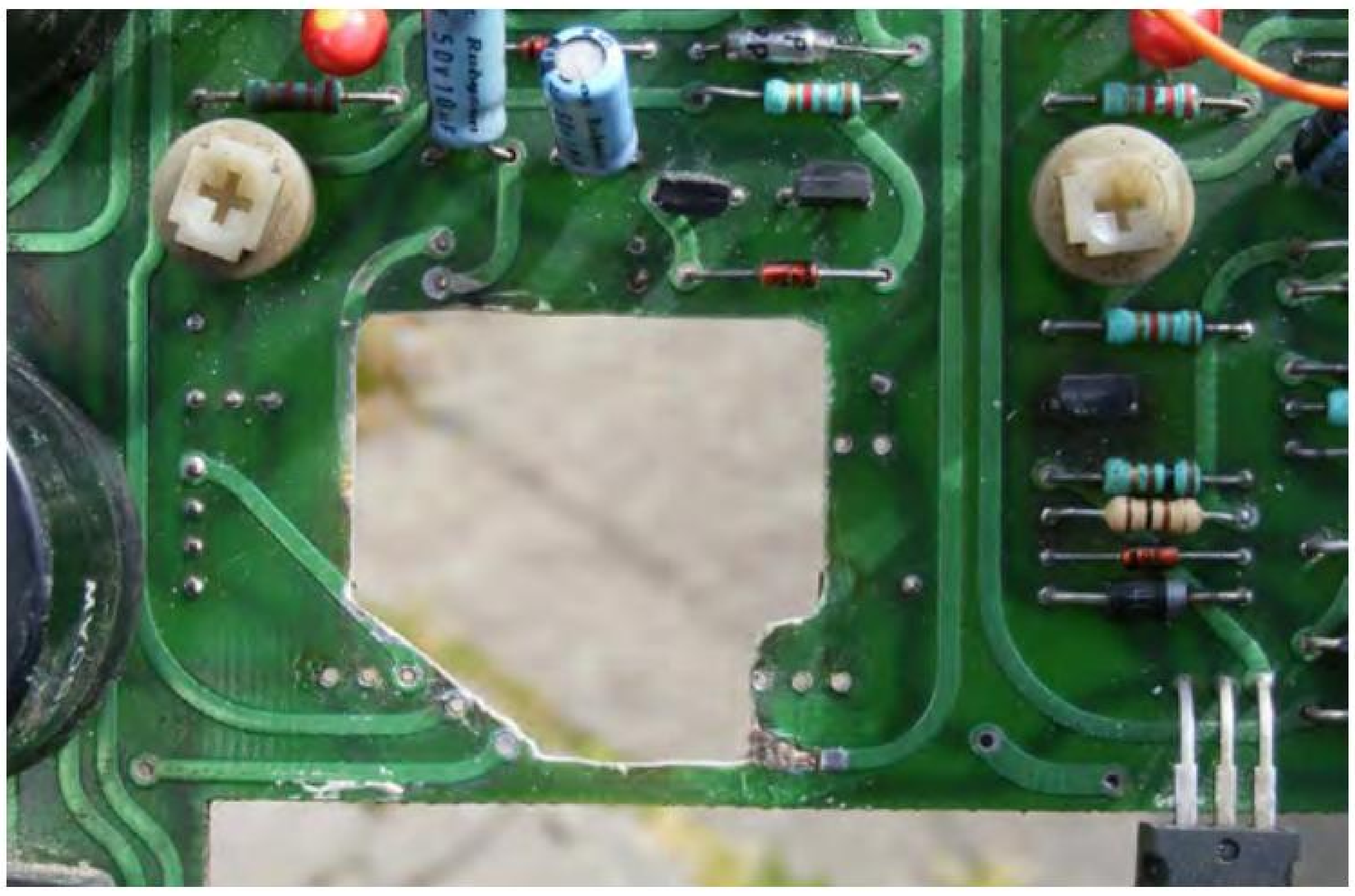

Fig.27. Here, the affected area of the Naim PCB has been cut out with a Dremmel.

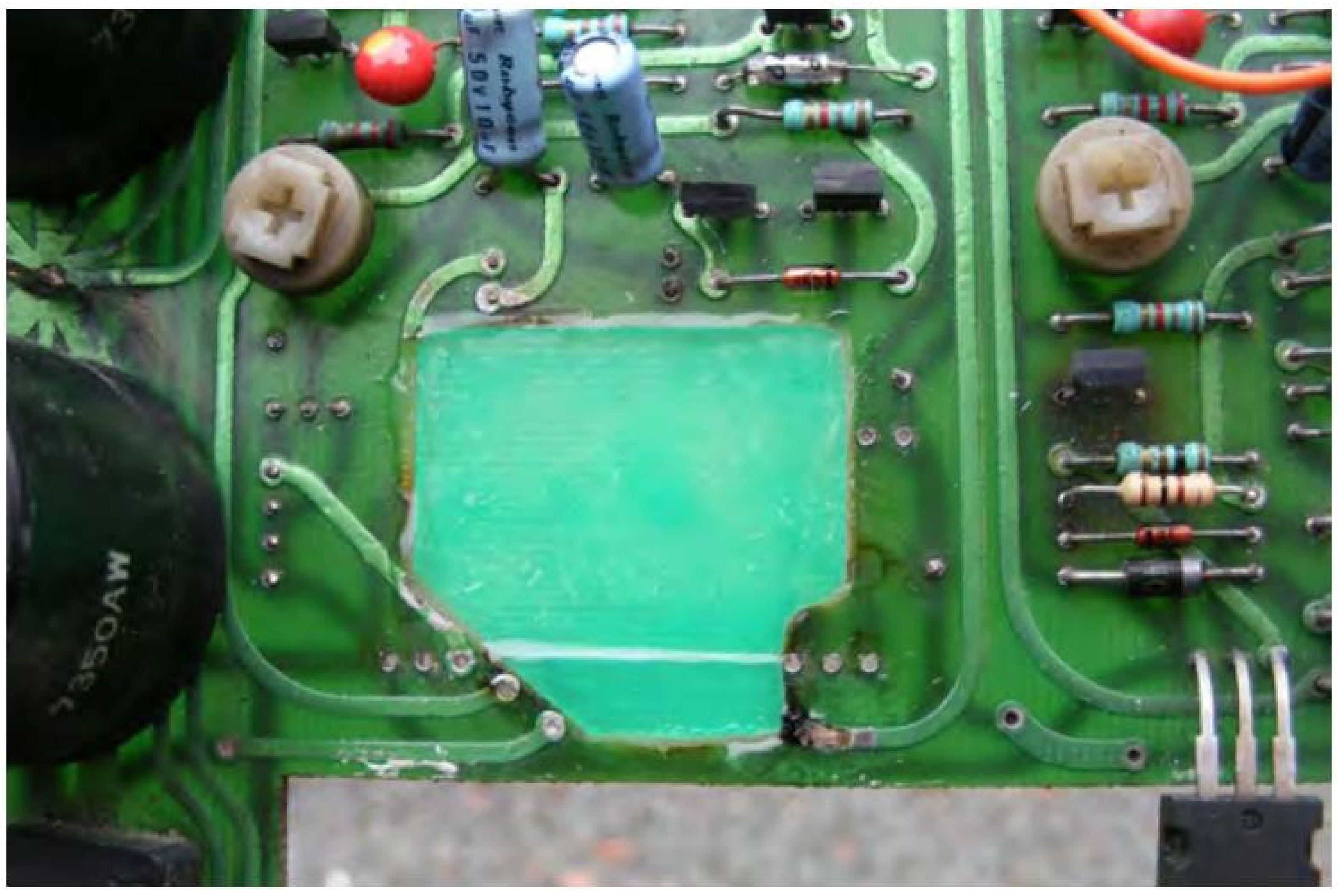

Fig.28. A new piece of board is epoxied in. I've now got to drill a load of holes and hard wire the new components. Hi-Fi obsessives claim fuses spoil the sound – I say the resulting fires from fuse-free designs are the poorer choice.

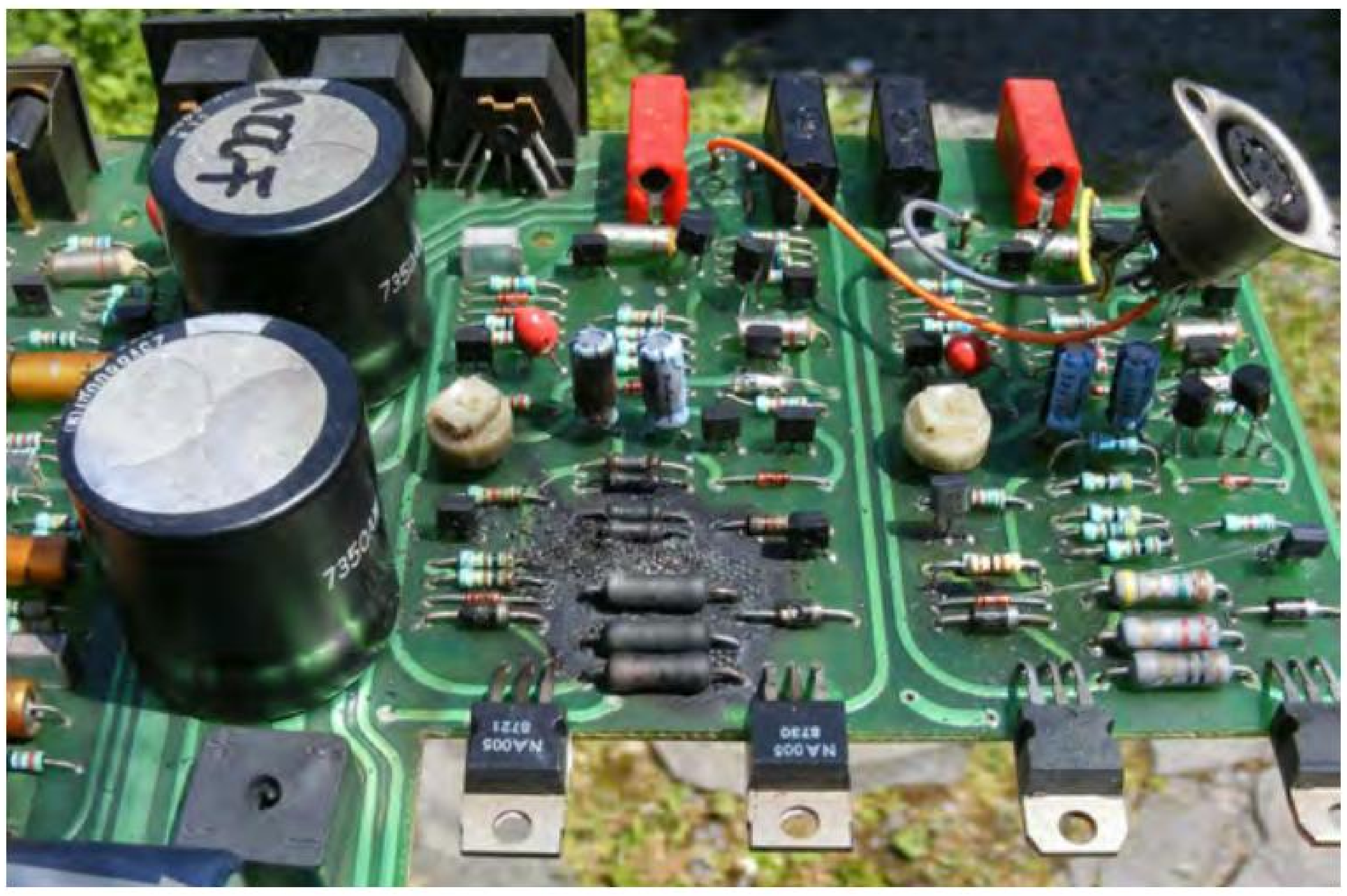

Fig.26. This valuable Naim amplifier had suffered a severe PCB burn-up. The owner wanted it repaired.

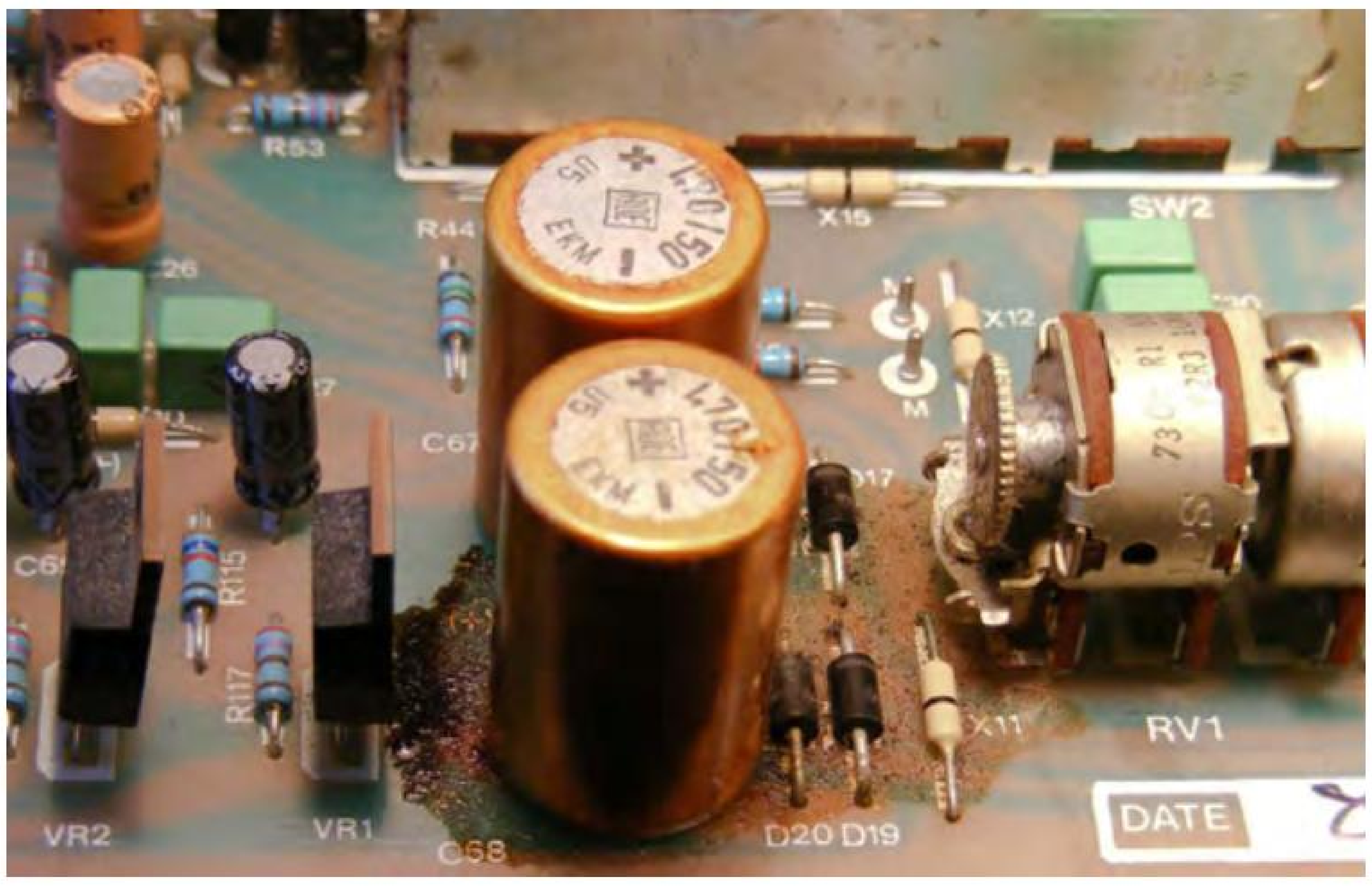

Fig.29. Leaking electrolytic capacitors can dissolve PCB tracks and components. The unique volume and balance potentiometer of this Mission Cyrus amplifier was saved just in time.

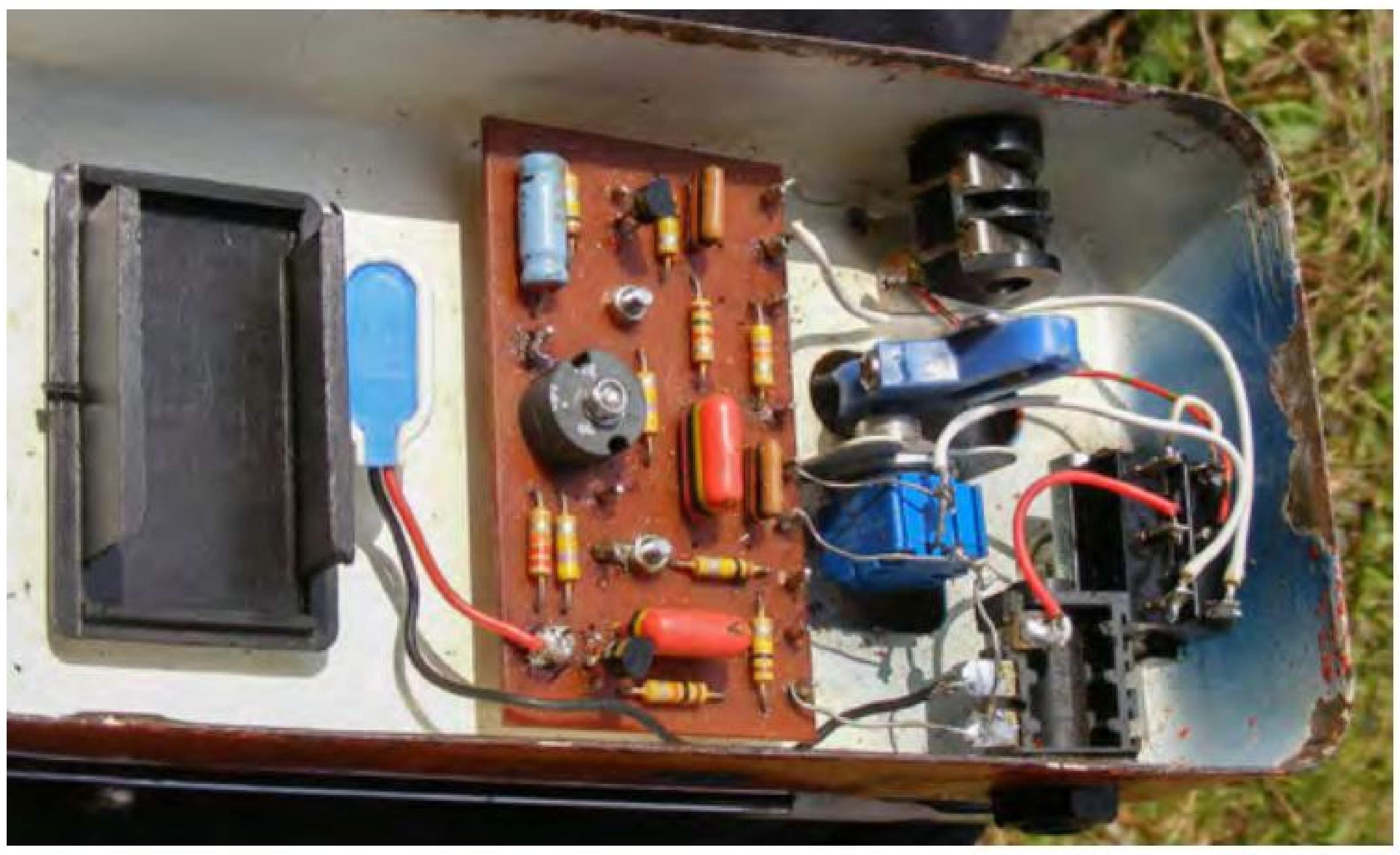

Fig.30. Inductors are normally very reliable, although those wound with fine wire often go open circuit at the terminations due to corrosion. A green colouration usually gives this away, and a bit of back winding and resoldering will effect a repair. I routinely do this on old Colorsound wah-wah pedals, such as this one from 1976.

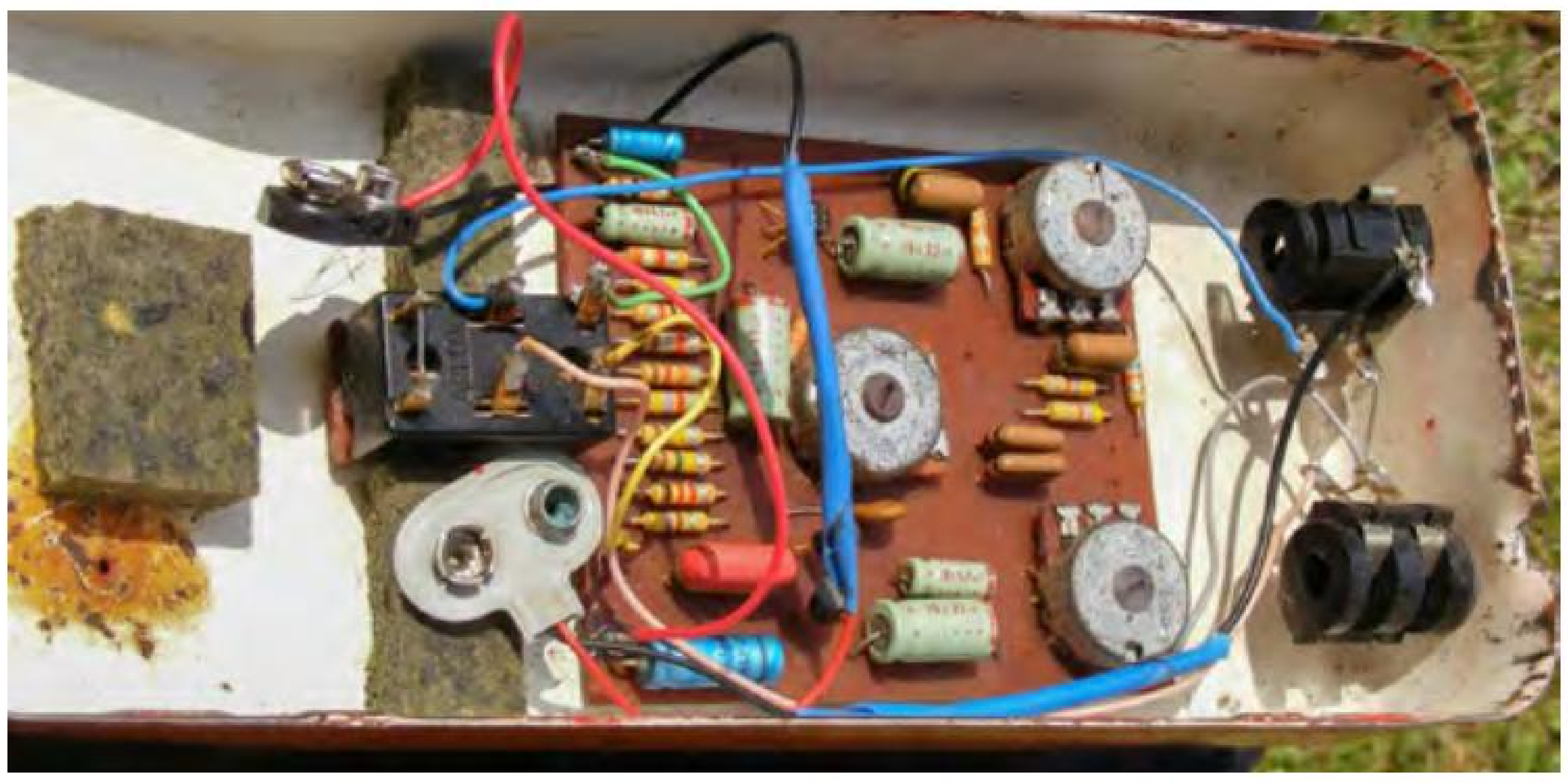

Fig.31. The rusty state of some old guitar pedals I get in for repair has to be seen to be believed. They are very rarely life-expired, just resurrected until the next time.

is very much part of British culture, people rebuild 1960s transistor radios and run heritage railways. My Victorian house was considered life-expired in the 1960s, but is now considered highly preferable to a timber-framed 'plastic' new-build. It just needs constant maintenance, but it is infinitely repairable. I do have one cut-off point, which is if it costs more to fix something than it costs to buy another working one second-hand, it should be scrapped or kept for spares.

I repaired an EMI mixing console for record producer Mike Hedges at his French studio. He sold it, and because of its Abbey Road Beatles provenance it fetched £1.8 million. Of course the engineering was truly excellent, apart from the BC109 transistors on the inputs that died when exposed to phantom power. Like a Stradivarius, this is one piece of equipment that will be loved and never life expired.

To summarise – repair and restoration is fun, satisfying but often frustrating! Nevertheless, it is definitely the right thing to do if you can.

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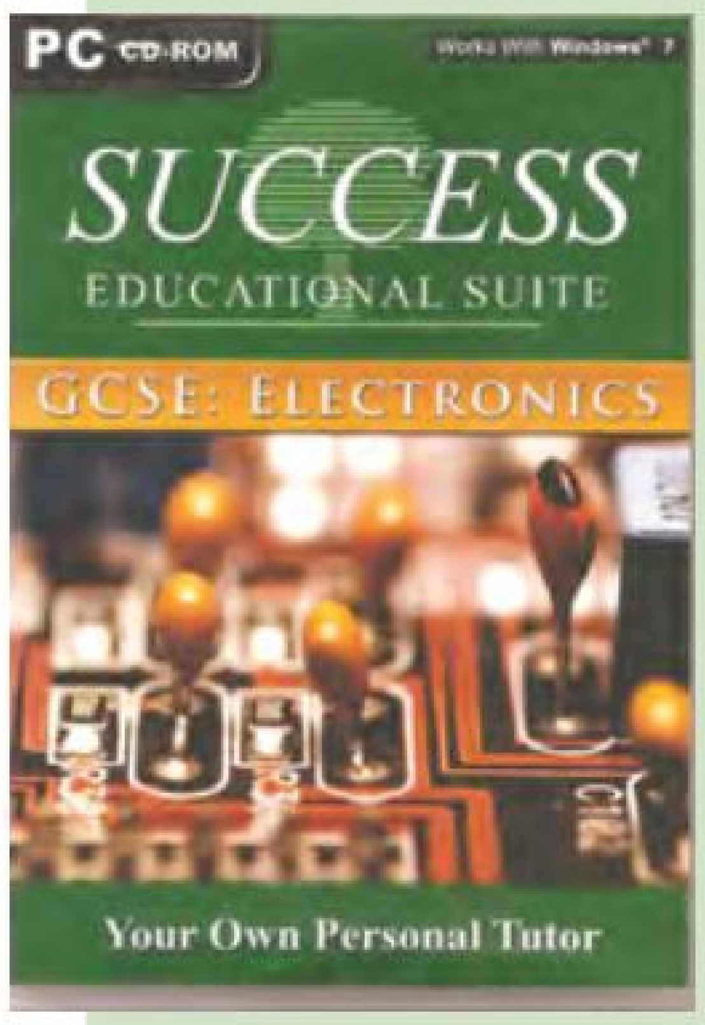

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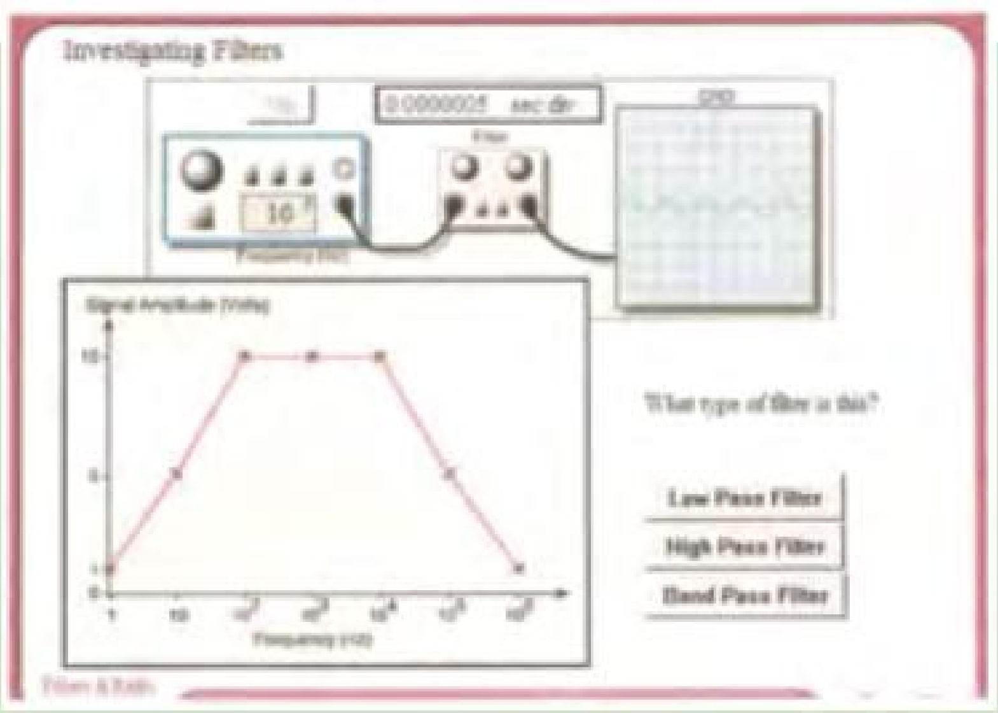

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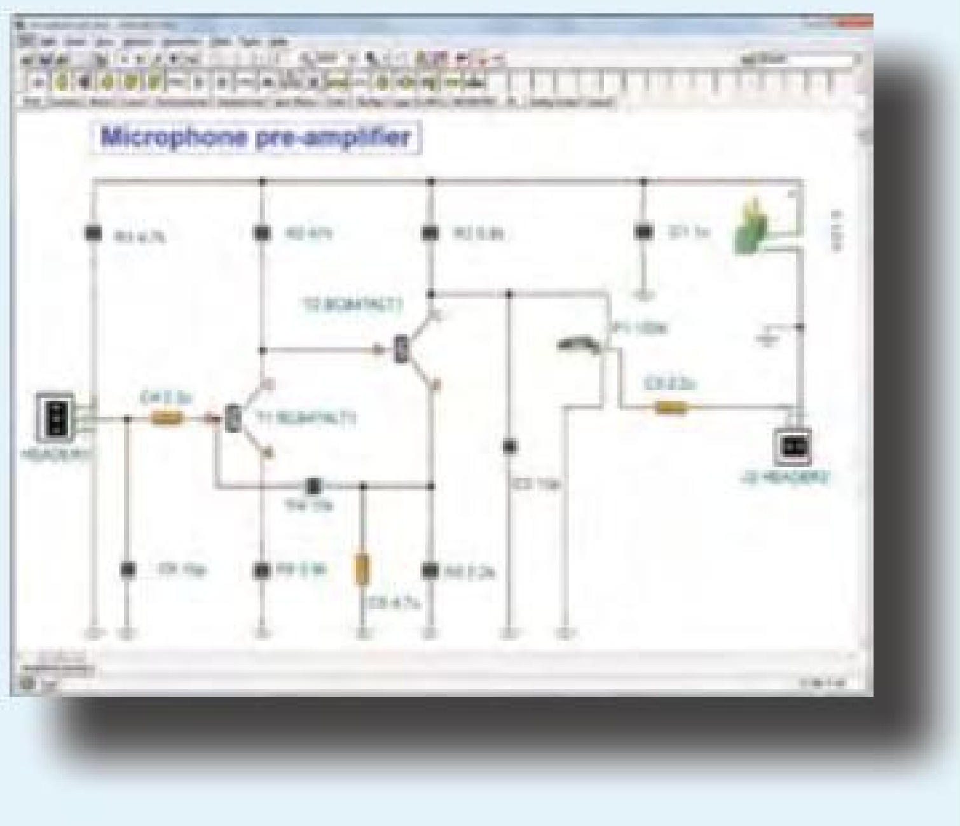

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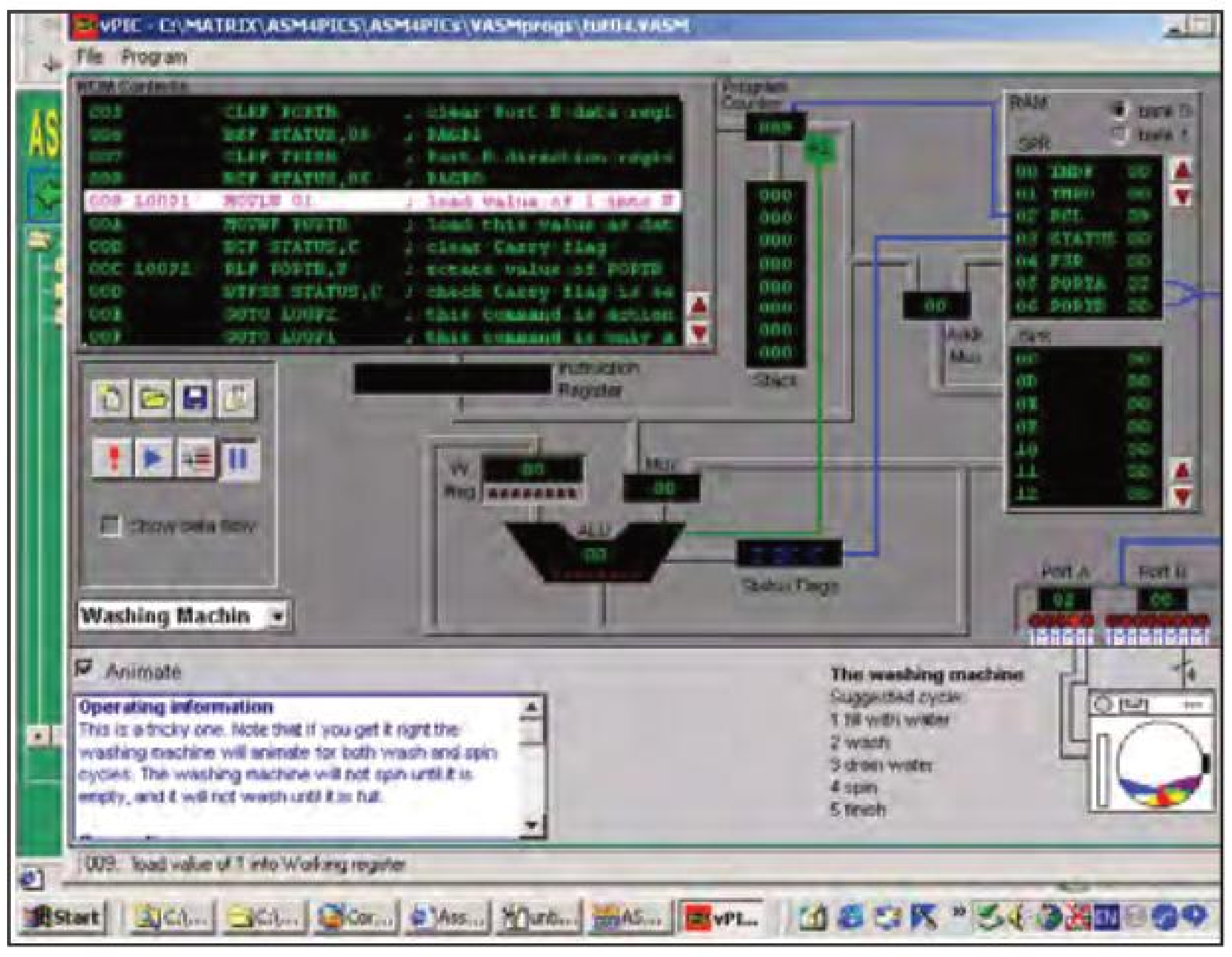

Operating information
This is a tricky one. Note that if you get it right the washing machine will animate for both wash and spin cycles. The washing machine will not spin until it is empty, and it will not wash until it is full.

The washing machine
Suggested cycle:
1 fill with water
2 wash
3 drain water
4 spin
5 finish

009: load value of 1 into Working register

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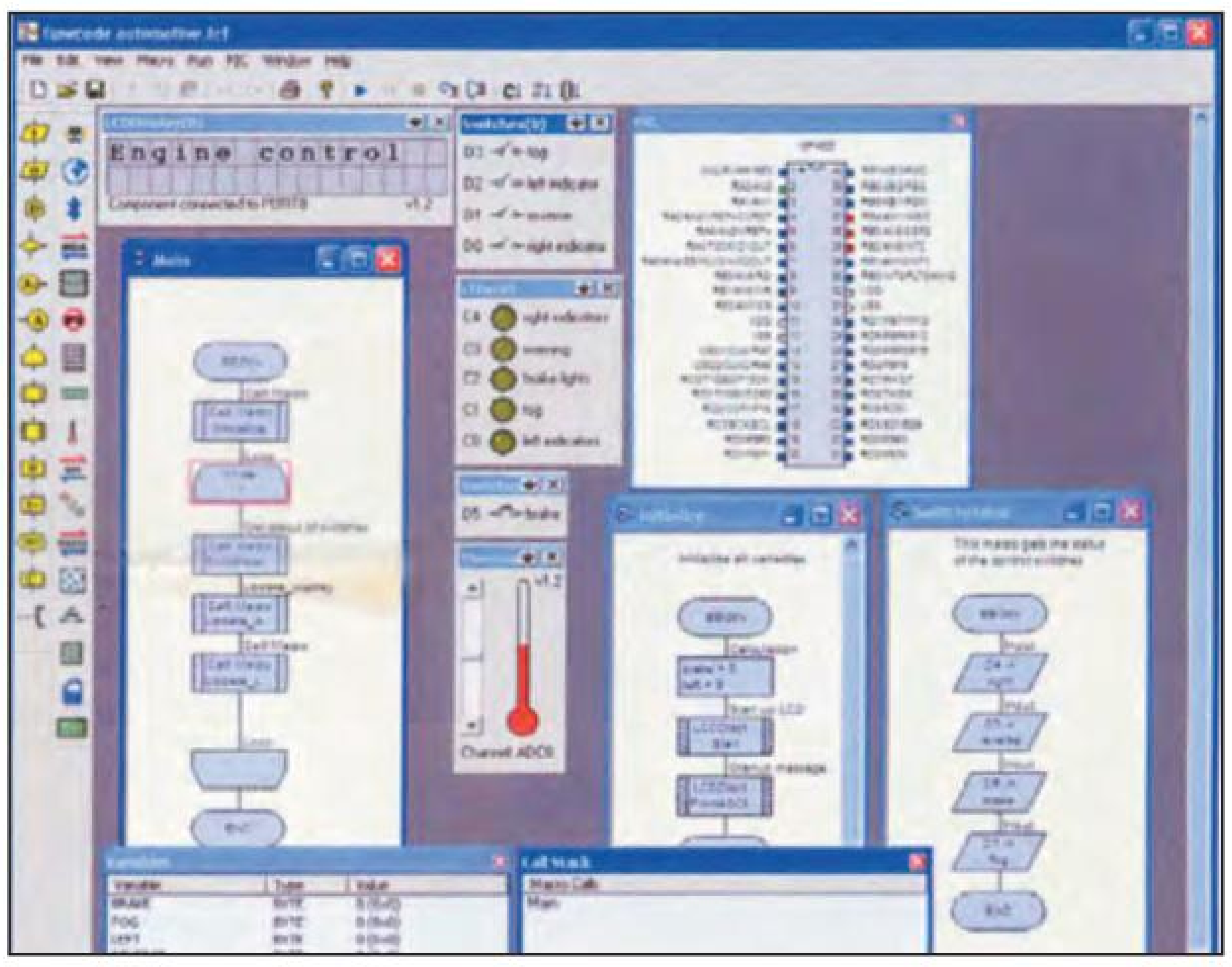

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This *Teach-In* series of articles was originally published in *EPE* in 2008 and, following demand from readers, has been collected together in the *Electronics Teach-In 2* CD-ROM.

The series is aimed at those using PIC microcontrollers for the first time. Each part of the series includes breadboard layouts to aid understanding and a simple programmer project is provided.

Also included are 29 *PIC N' Mix* articles, also republished from *EPE*. These provide a host of practical programming and interfacing information, mainly for those that have already got to grips with using PIC microcontrollers. An extra four part beginners guide to using the C programing language for PIC microcontrollers is also included.

The CD-ROM also contains all of the software for the *Teach-In 2* series and *PIC N' Mix* articles, plus a range of items from Microchip – the manufacturers of the PIC microcontrollers. The material has been compiled by Wimborne Publishing Ltd. with the assistance of Microchip Technology Inc.

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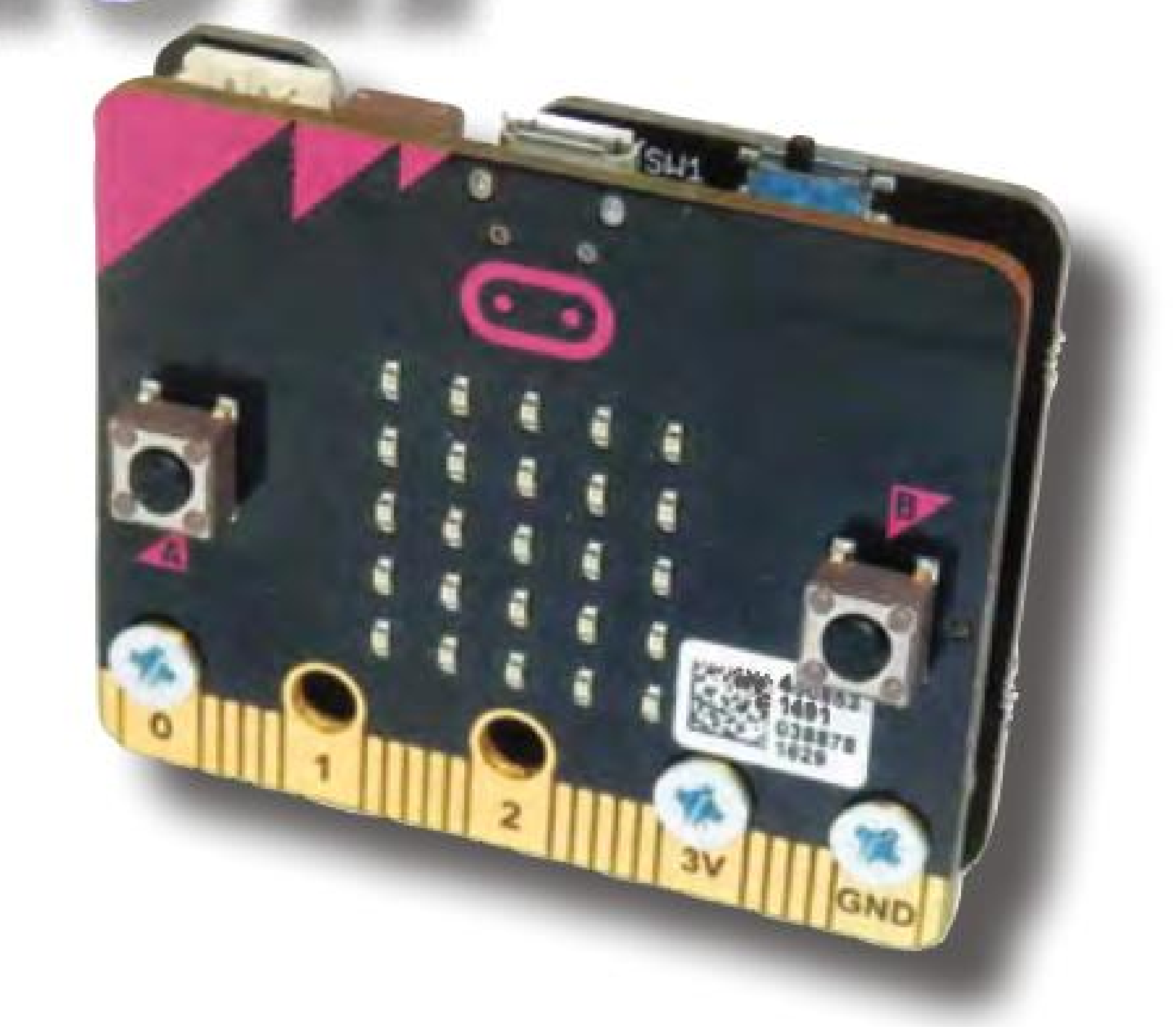

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PYTHON CODING ON THE BBC MICRO:BIT
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Python is the leading programming language, easy to learn and widely used by professional programmers. This book uses MicroPython, a version of Python adapted for the BBC Micro:bit.

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Not just an educational resource for teaching youngsters coding, the BBC micro:bit is a tiny low cost, low-profile ARM-based single-board computer. The board measures 43mm × 52mm but despite its diminutive footprint it has all the features of a fully fledged microcontroller together with a simple LED matrix display, two buttons, an accelerometer and a magnetometer.

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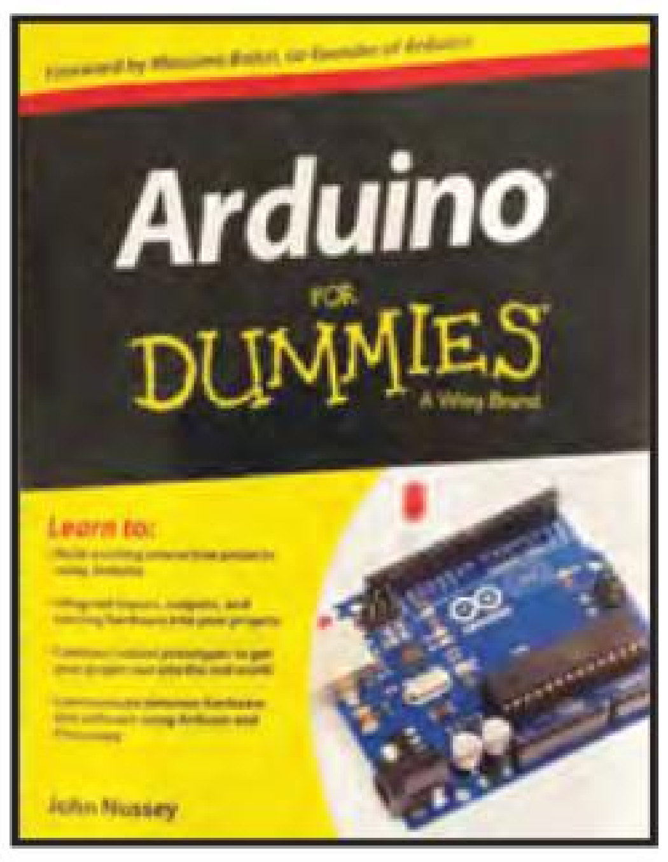

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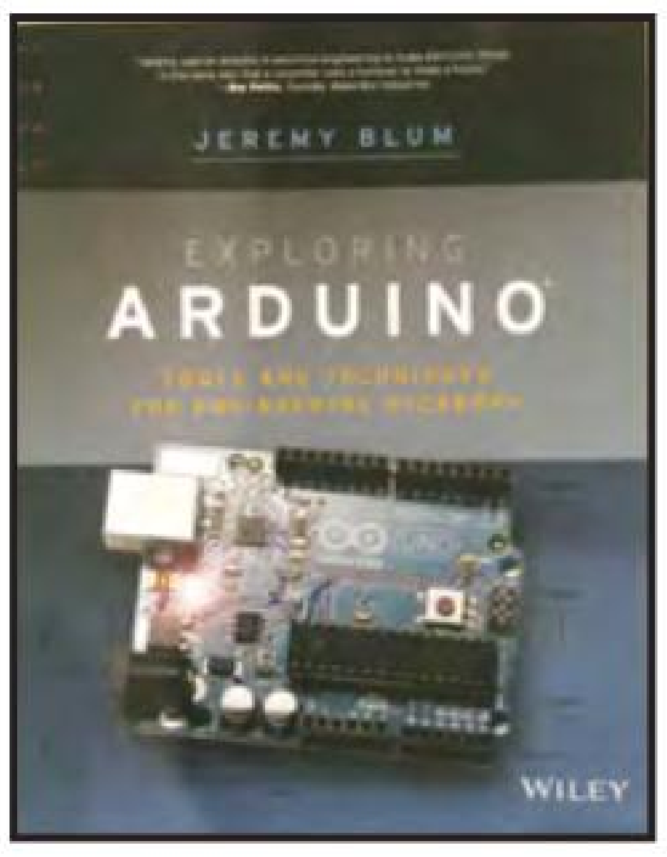

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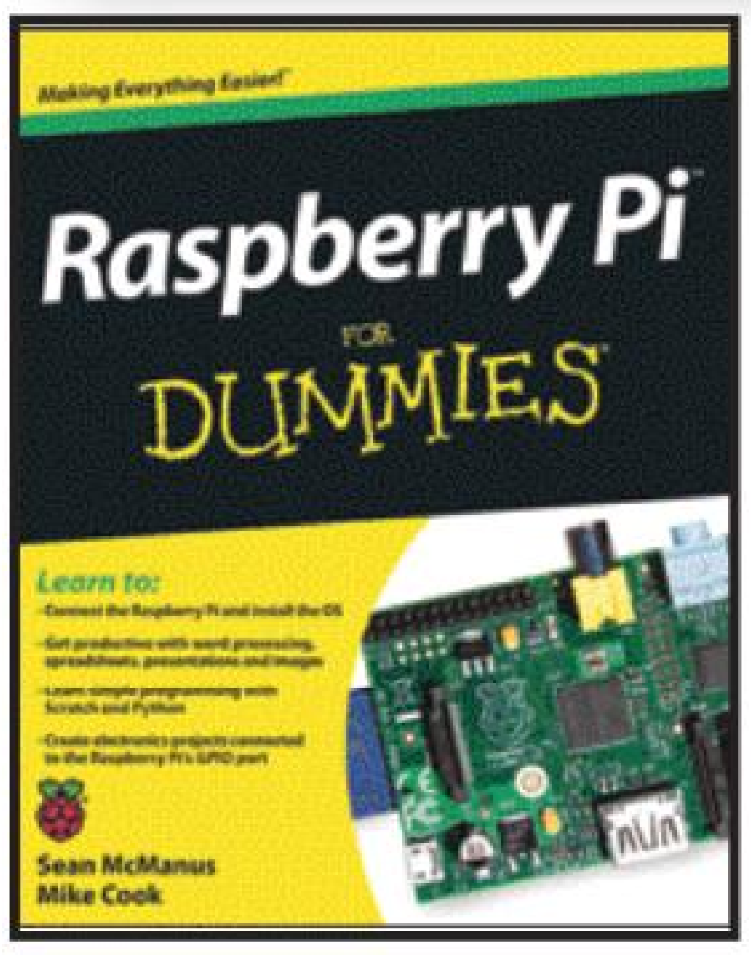

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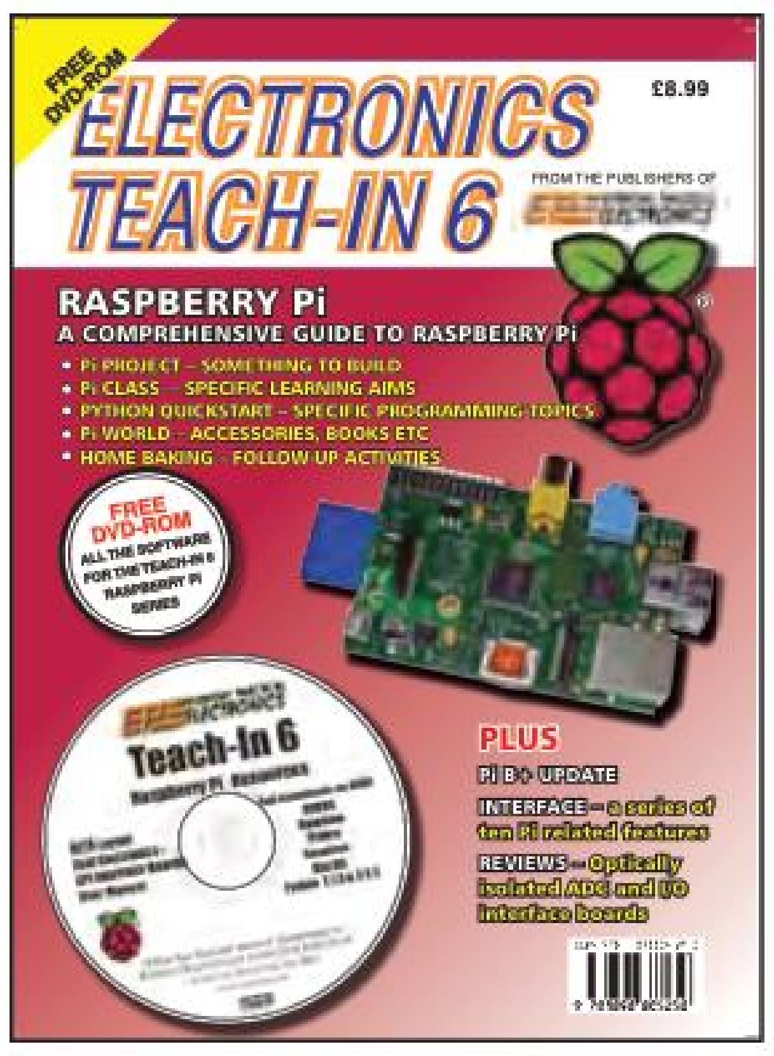

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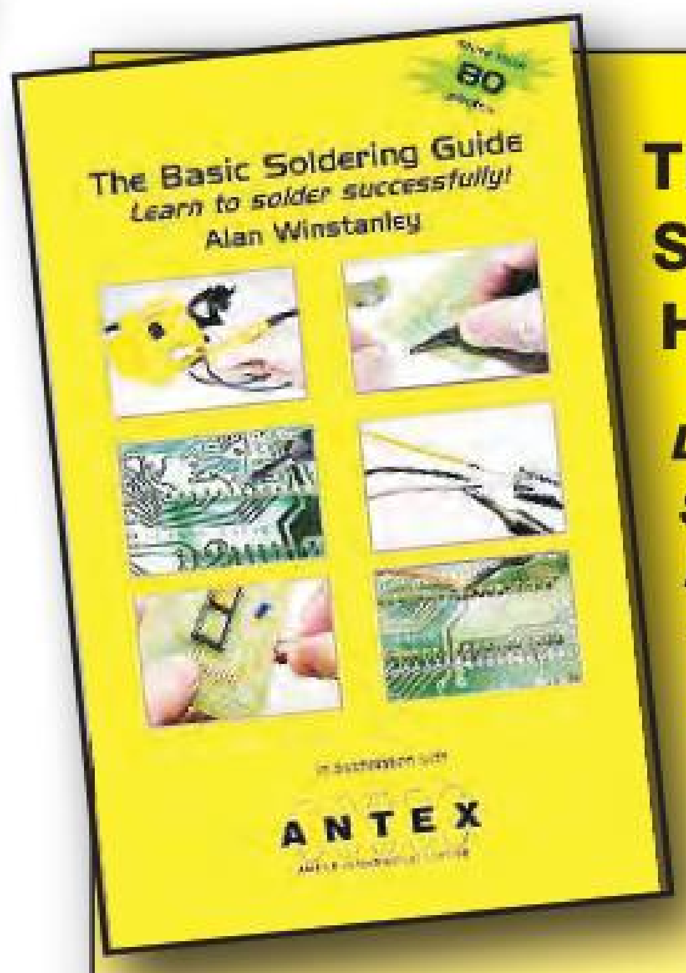

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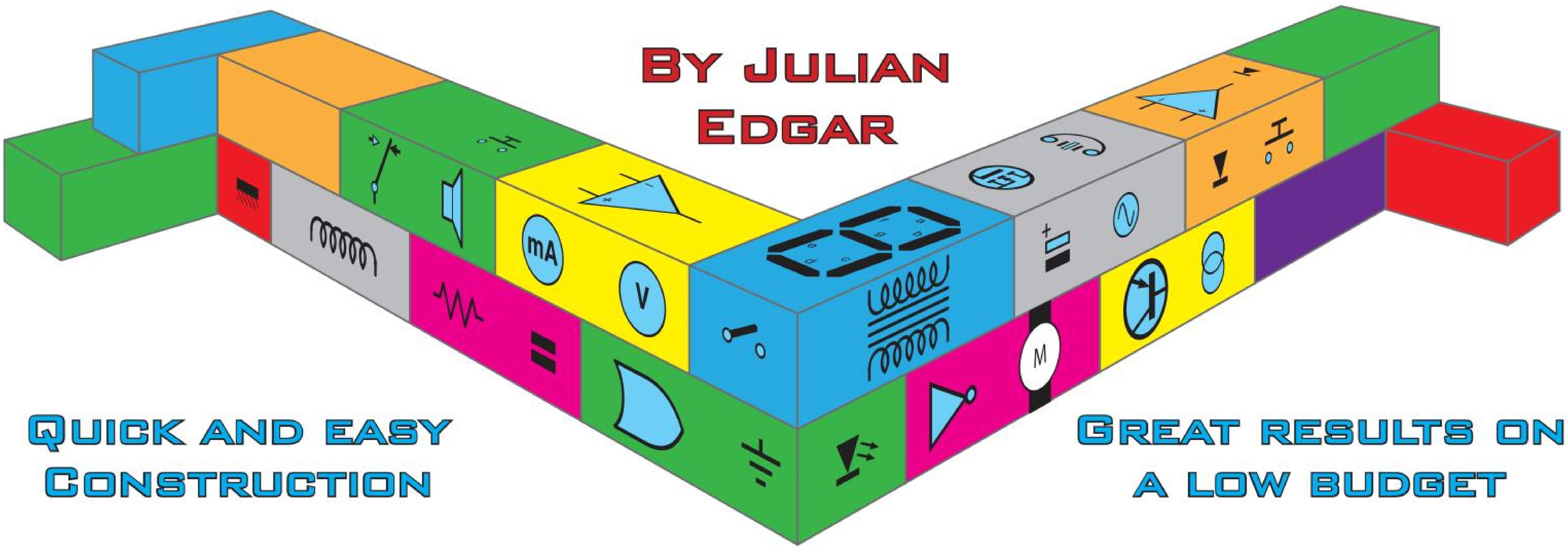


By Julian Edgar

Quick and easy Construction

Great results on a low budget

Machine Tool Digital Tachometer

Large complex projects are fun, but they take time and can be expensive. Sometimes you just want a quick result at low cost. That's where this series of *Electronic Building Blocks* fits in. We use 'cheap as chips' components bought online to get you where you want to be... FAST! They represent the best value we can find in today's electronics marketplace!

Do you have a home workshop equipped with different machine tools; for example, a drill press, lathe or mill? If so, you'll love the module that's presented this month. It's a 4-digit tachometer that reads up to 9999 RPM – perfect for measuring the spindle speed on a lathe or drill press. The tachometer costs under £7 (including delivery) and is easy to set up and power.

But first, why would you want to measure the spindle speed of a machine tool? Many tools have adjustable speed, either by swapping pulleys on a belt drive (eg, a drill press or vertical mill), changing gears (eg, in a metalworking lathe) or by using a belt-drive with a variable diameter cone system (eg, a woodworking lathe). In all cases, slower speeds are used when making heavier cuts, while higher speeds are used for fine cuts and finishing. Also, the smaller the drill diameter, the faster the speed you'll want to use.

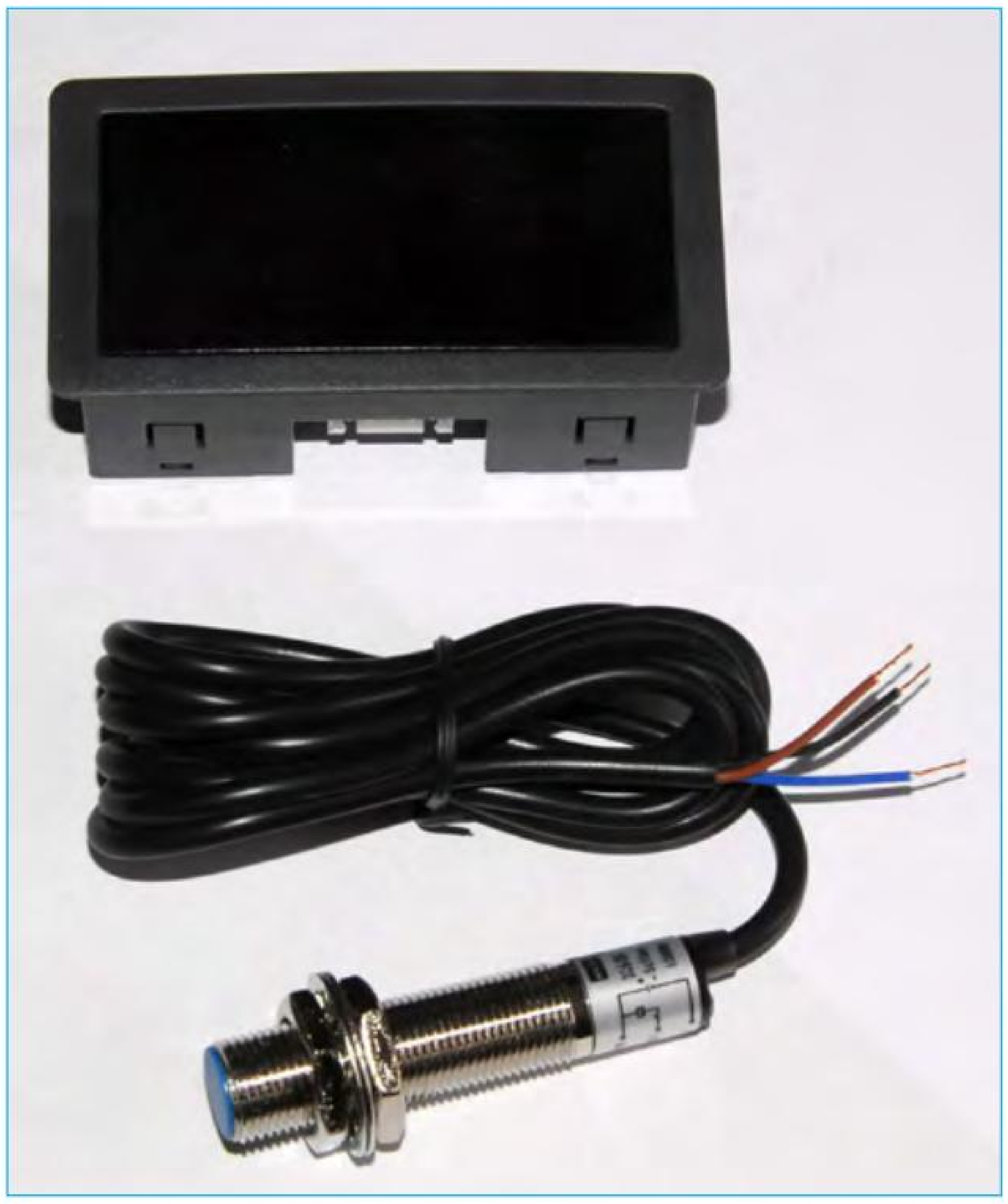


Fig.1. This digital tachometer can read from 5 – 9999 rpm and comes complete with Hall sensor. It's ideal for measuring and displaying the speed of machine tools in a home workshop.

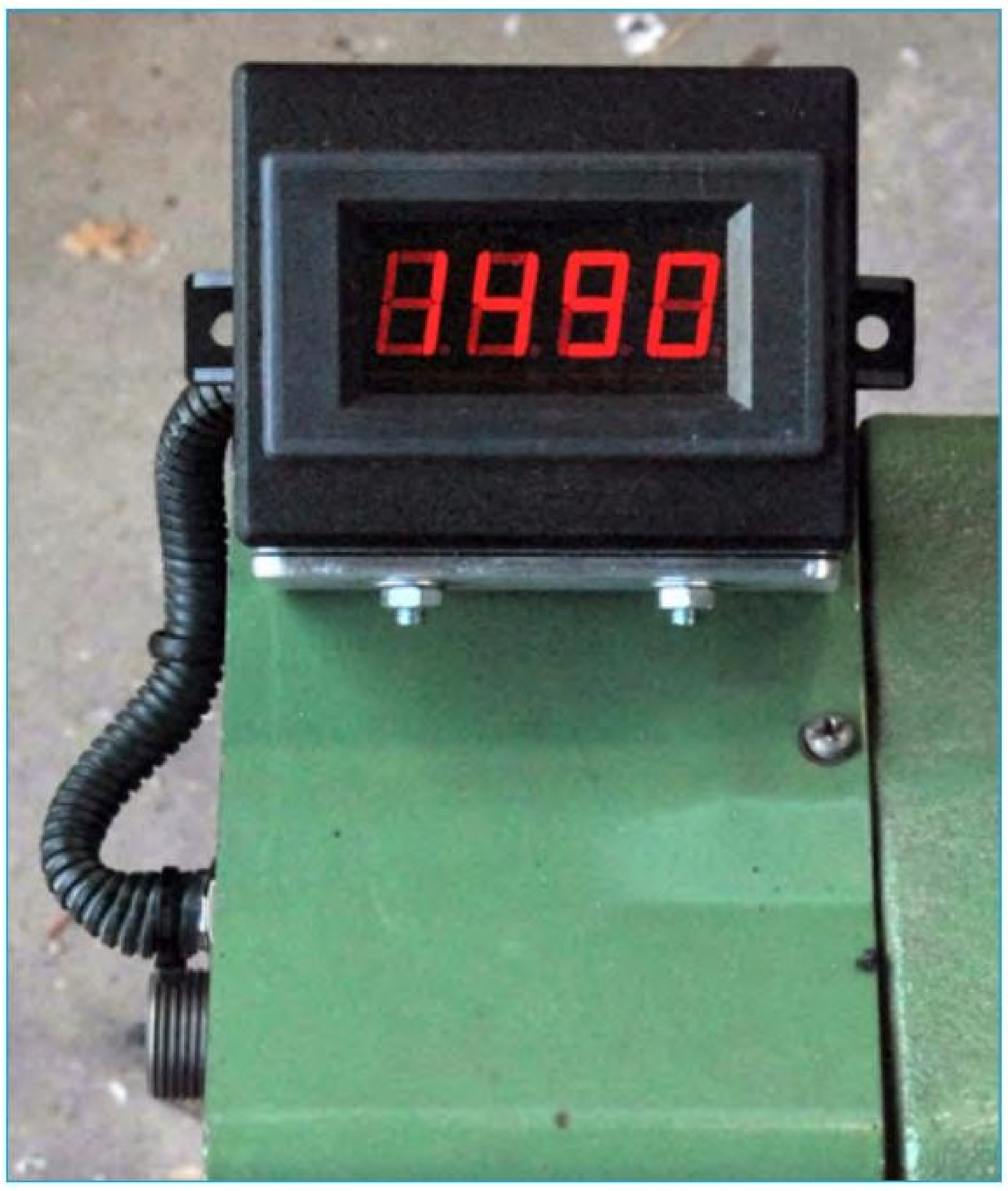


Fig.2. The digital tachometer installed on a woodturning lathe. The red display is a little hard to read in a brightly lit workshop (although better than it appears here), so later I replaced the tachometer with another that has a blue display.

But how do you know how fast the spindle is turning? In most cases this requires inspection of the settings of the drive mechanism (eg, which pulley is driving which) and then some calculations. Sure, it's possible – but glancing at a digital display is so much quicker and easier!

The module

The module comes built into a case that can be flush-mounted in a panel. Overall size is 79 × 49 × 25mm, while the display window cut out is 67 × 32mm. The digits themselves are 15mm high – easy to read up to a metre away. The reading is heavily filtered – I measured about a five-second time constant – and so if there are very rapid changes in RPM (eg, of a car engine) then the display will lag behind the actual speed. In a machine tool application, this lag is not important.

The module is powered by a DC supply that can be anywhere in the range of 8 – 24V. Current consumption is only 30 or 40mA (the actual value depends on the display) and so any plug-pack that operates in this voltage range can be used. (You probably

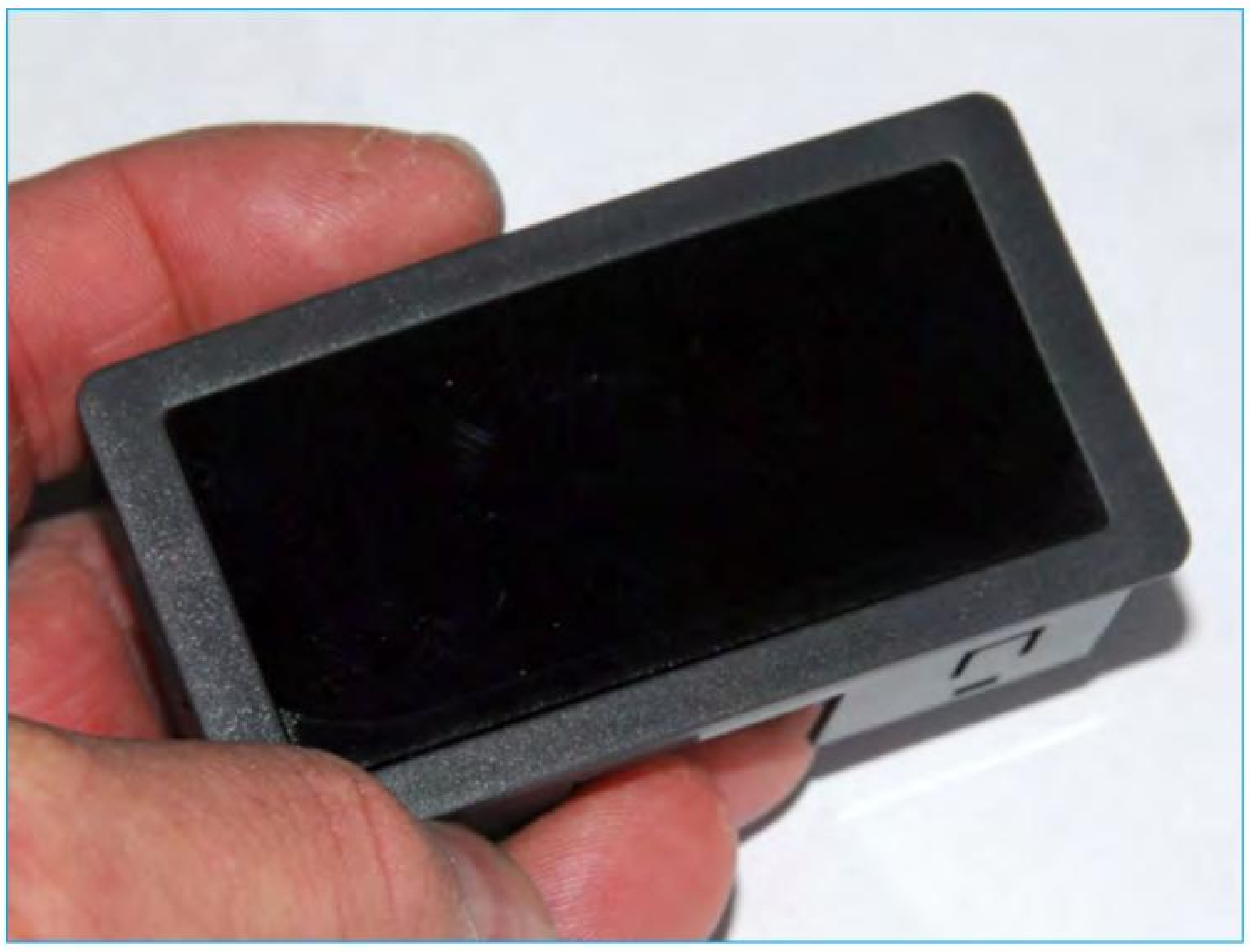


Fig.3. The tachometer module uses a large display with 15mm-high digits, making it easy to read from a distance.

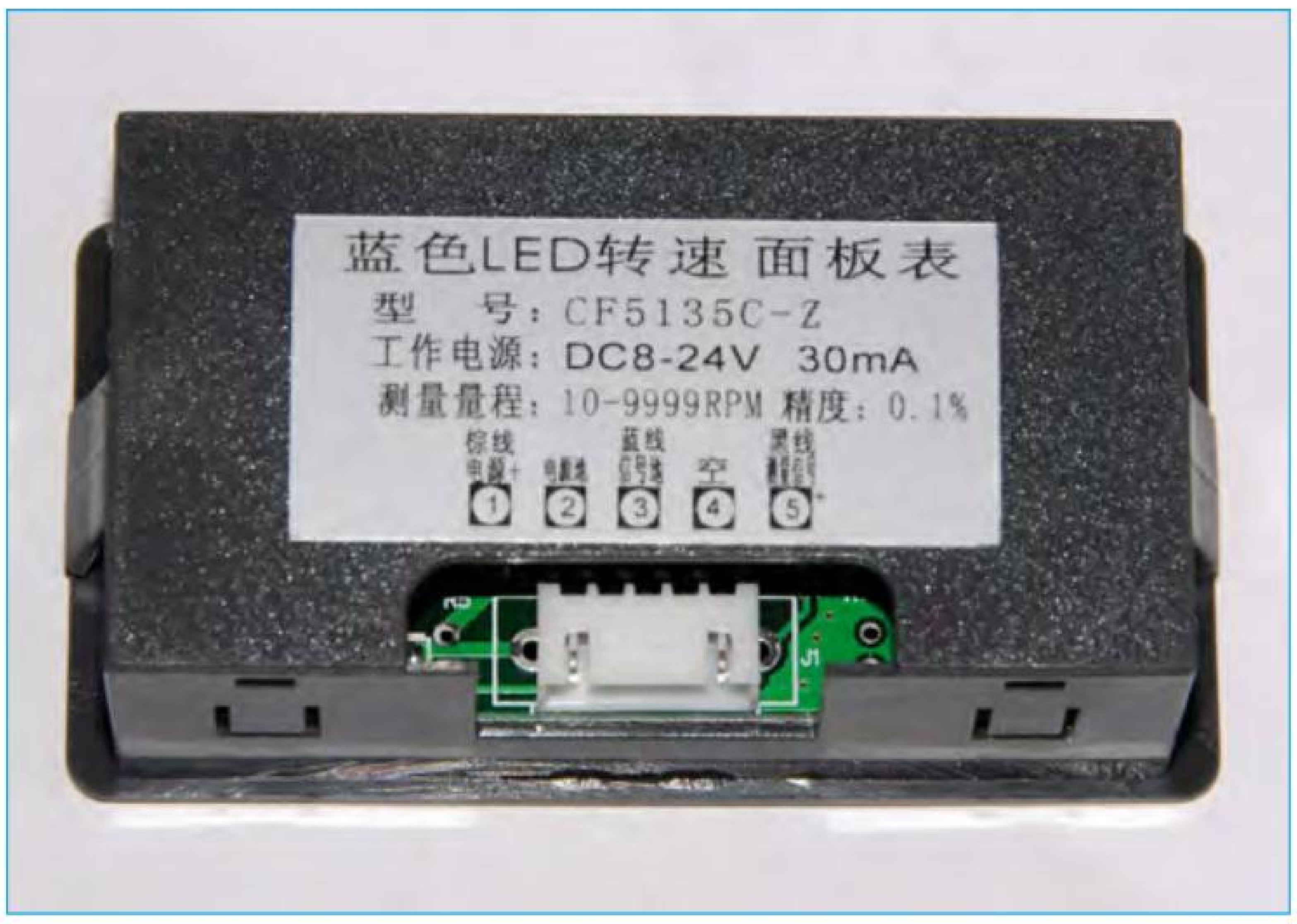
already have a suitable discarded plug-pack on the shelf.) If you wish to, you could power the tachometer from a 9V battery instead – in that case, don't forget to add an on/off switch.

The sensor used to detect rotation is a Hall proximity switch. The sensor needs to be positioned so that it can detect the passing of a small magnet (the magnet is *not* supplied). The sensor is quite large (56 × 21mm) and uses an M12 threaded body, complete with adjustable nuts and washers.

The modules are available with red, blue and green displays. I initially bought one with a red display, but found it hard to read in a brightly illuminated home workshop. (I later swapped to a blue display, which I found much easier to read and despite the photo shown here, that is what I recommend you use.).

Connection to the module is via four wires, with a plug and short length of cable supplied for the on-board socket. The module with the red display had self-explanatory wiring, with the connections for both power and the sensor pre-wired with matching plugs and sockets. However, the module with the blue display was a little trickier, with the labels not in English. The blue module used the following connections:

1 – Power
2 – Ground
3 – Signal ground
4 – Not used
5 – Signal input



This version of the module does not come with English connection instructions, but the pin connections are described in the main text.

The connections on the sensor were:

Brown – Power
Blue – Ground
Black – Signal

To find the tacho, search **eBay.co.uk** (eg, item 262844561486) or **www.banggood.com** under '4 Digital LED Tachometer RPM Speed Meter + Proximity Switch Sensor NPN'.

Fitting the module

The trickiest part of fitting the tachometer is mounting the sensor and its magnet. The best approach is to find a large pulley or drive cog that rotates at output shaft speed. Clean the surface thoroughly and then glue a small magnet to the flat surface of the drive pulley or cog. Mount the sensor on a bracket so that it is 'aimed' at the magnet but clears it by a small amount. The threaded body of the sensor can be used to adjust the clearance between the sensor and magnet.

If you are fitting the tachometer to a metal-cutting tool, position the magnet so that it will not attract ferrous swarf.

I mounted the tachometer on my woodturning lathe. The display was placed in a utility box and a salvaged plug-pack used to power the system. It works really well.

Next time

In my next column I'll be looking at a *Simple Remote Control*.

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PCB SERVICE

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Basic printed circuit boards for most recent *EPE* constructional projects are available from the *PCB Service*, see list. These are fabricated in glass fibre, and are drilled and roller tinned, but all holes are a standard size. They are not silk-screened, nor do they have solder resist. Double-sided boards are **NOT plated through hole** and will require 'vias' and some components soldering to both sides. **NOTE: PCBs from the July 2013 issue with eight digit codes** have silk screen overlays and, where applicable, are double-sided, plated through-hole, with solder masks, they are similar to the photos in the relevent project articles.

All prices include VAT and postage and packing. Add £2 per board for airmail outside of Europe. Remittances should be sent to **The PCB Service, Everyday Practical Electronics, Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset BH21 1UU. Tel: 01202 880299; Fax 01202 843233; Email: orders@epemag.wimborne.co.uk. On-line Shop: www.epemag.com**. Cheques should be crossed and made payable to *Everyday Practical Electronics* **(Payment in £ sterling only)**.

NOTE: While 95% of our boards are held in stock and are dispatched within seven days of receipt of order, please allow a maximum of 28 days for delivery – overseas readers allow extra if ordered by surface mail.

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Touchscreen Appliance Energy Meter – Part 2

Following June's introduction of the *Appliance Energy Meter*, next month we'll take you through the process of building the PCBs and assembling the whole unit, as well as describing some of the fascinating features of the meter's software.

'Banggood' DSO138 LCD Scope Kit

Fancy a digital sampling oscilloscope? How about a new one for under £24? Of course you do – but surely that's impossible! Well, if you're prepared to assemble a simple kit from Chinese vendor Banggood then you can have a basic, but perfectly useable instrument for very little outlay.

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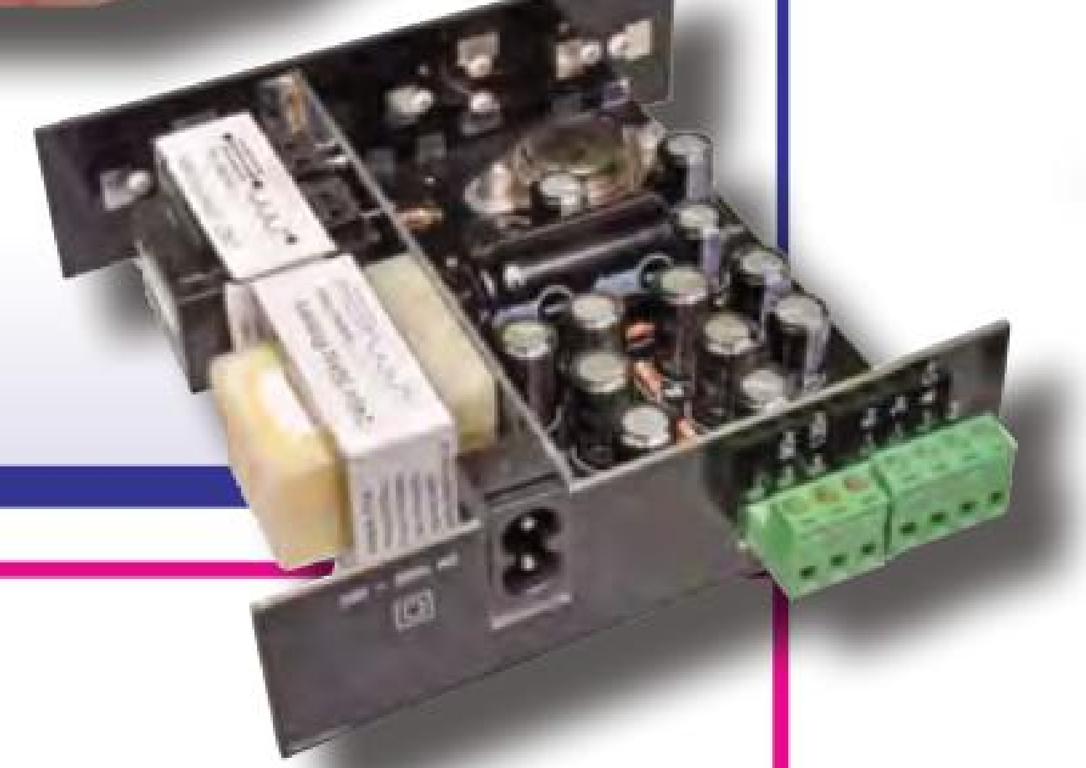
Low-cost Electronic Modules – Part 8

Next month, we look at Li-Ion and LiPo charger modules. One is low cost and has a simple design, while the other sports an inbuilt DC-DC boost converter to provide a regulated output voltage from the Li-ion/LiPo cell, taking account of voltage variation during charge/discharge cycles.



Power Supply for Battery-operated Valve Radios

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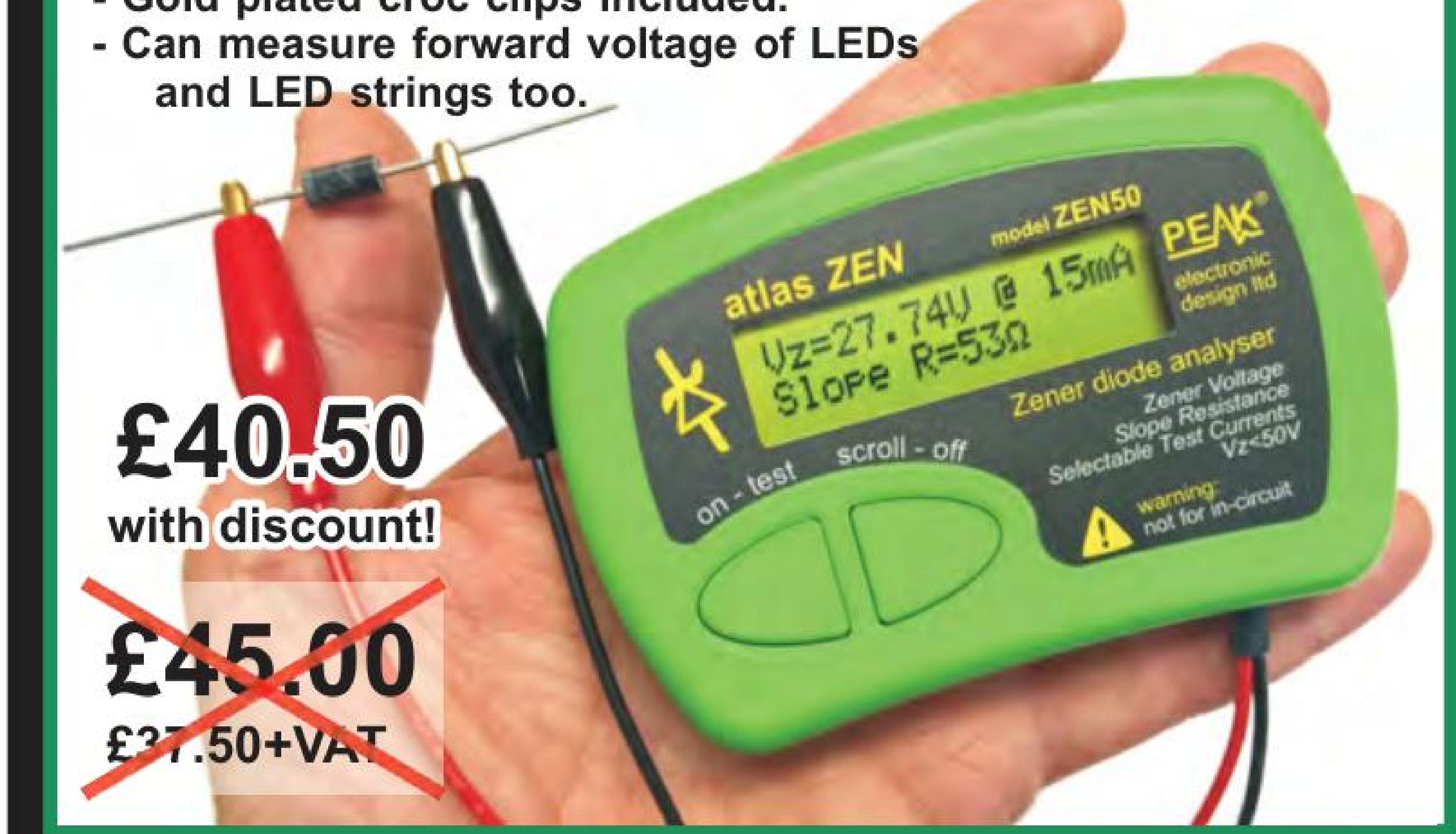
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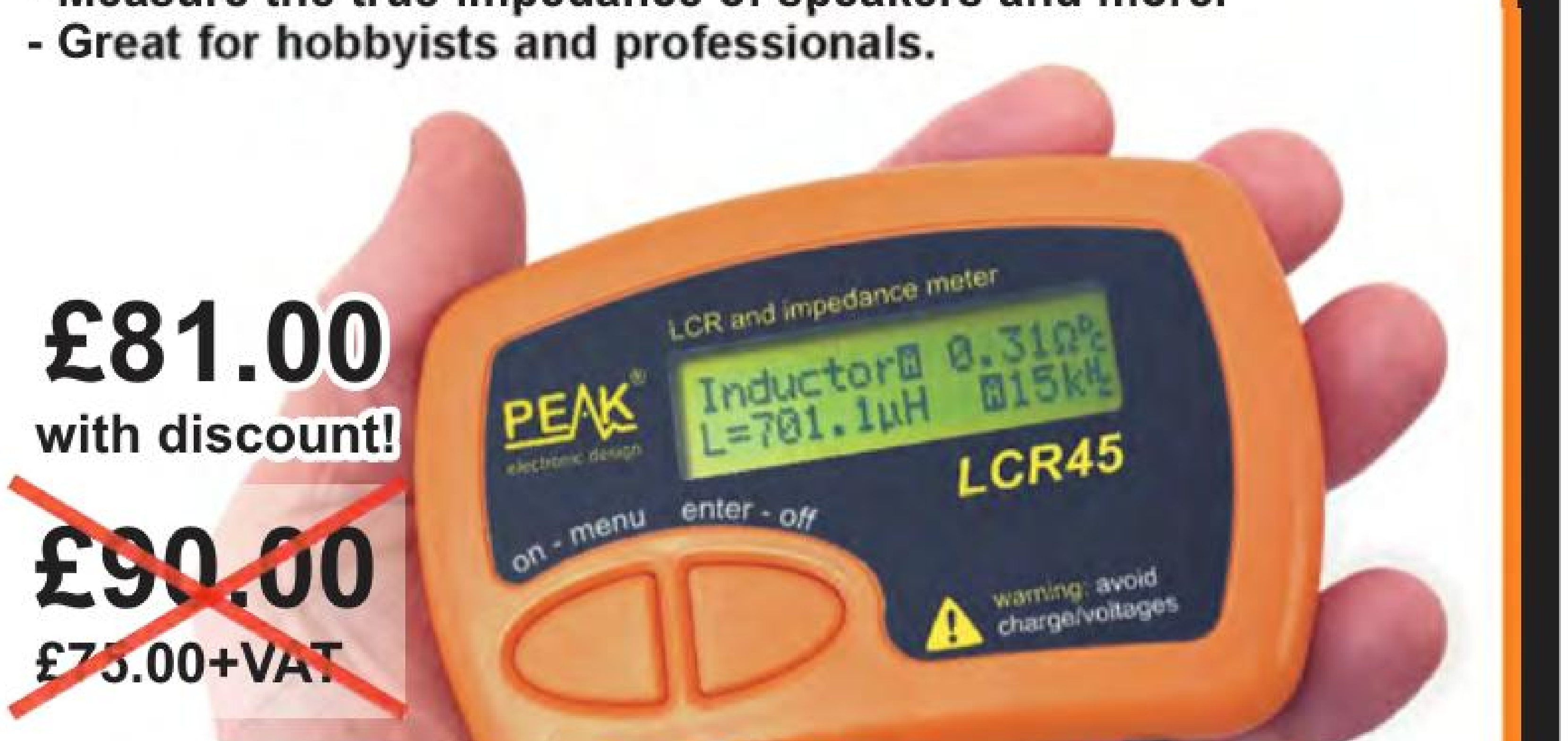
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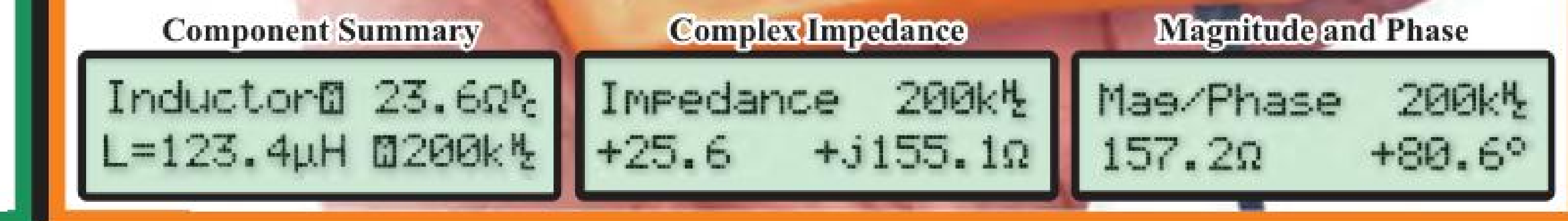

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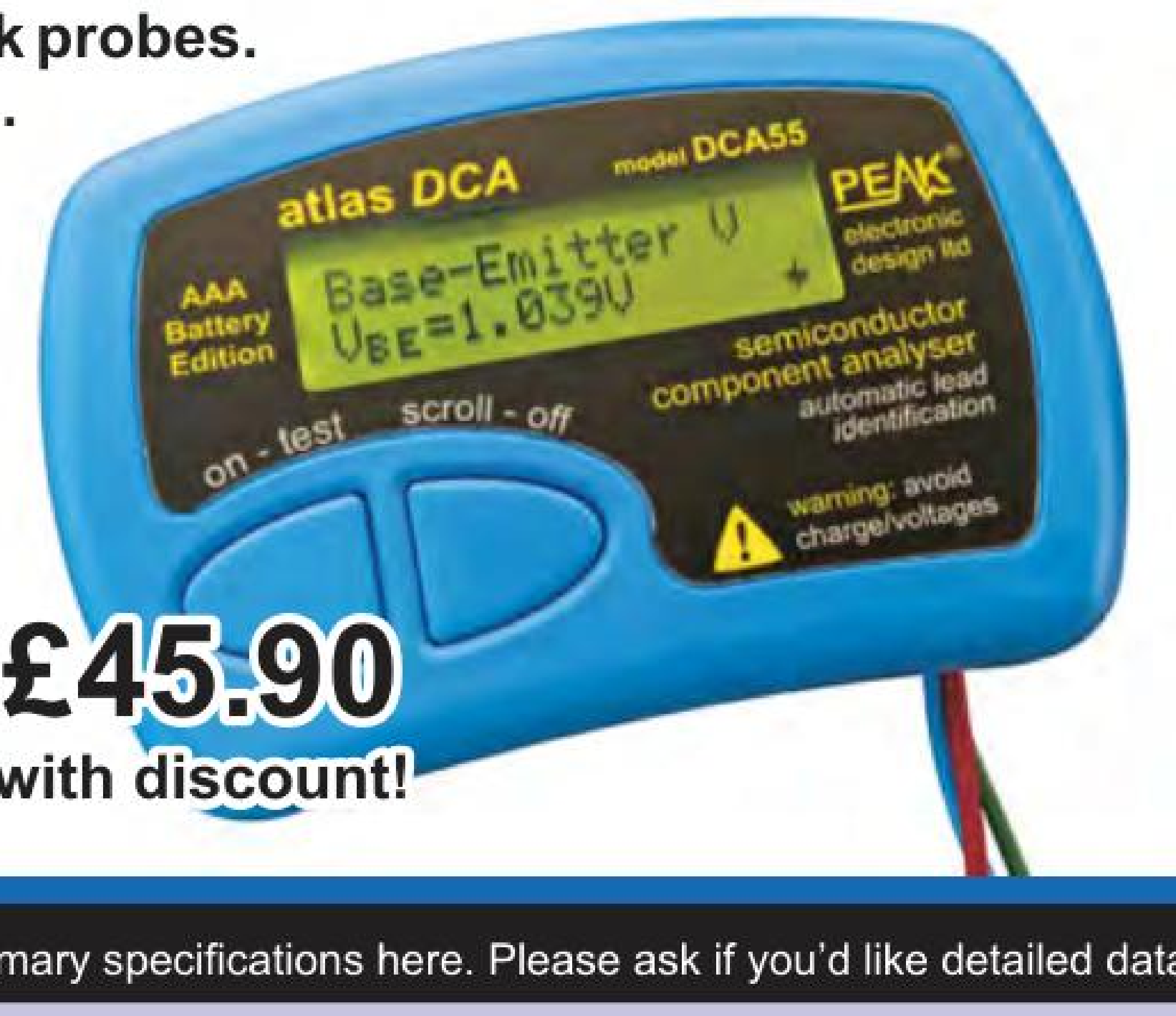
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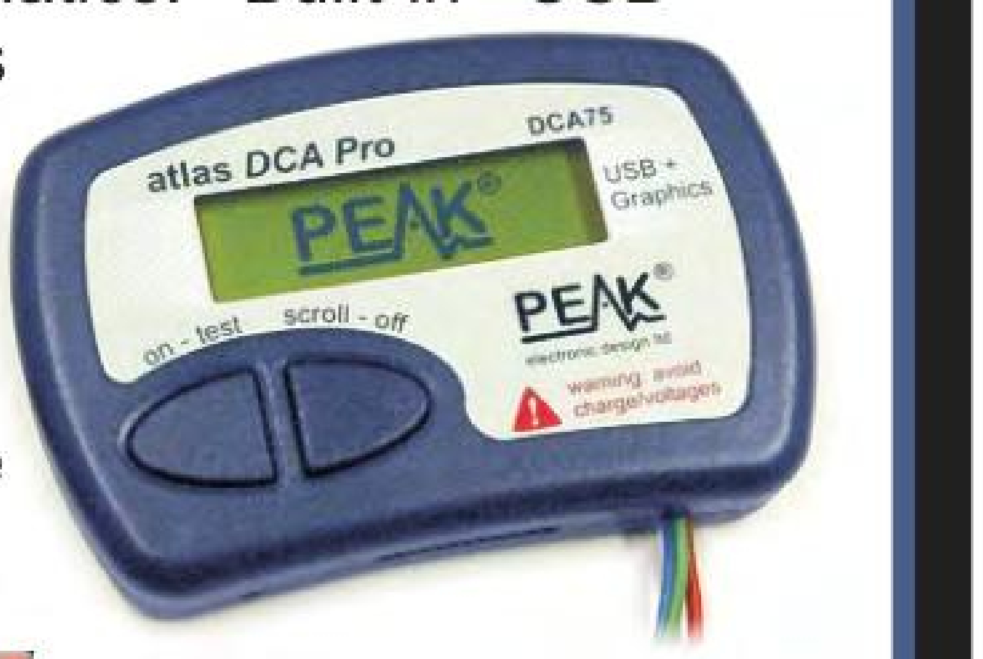
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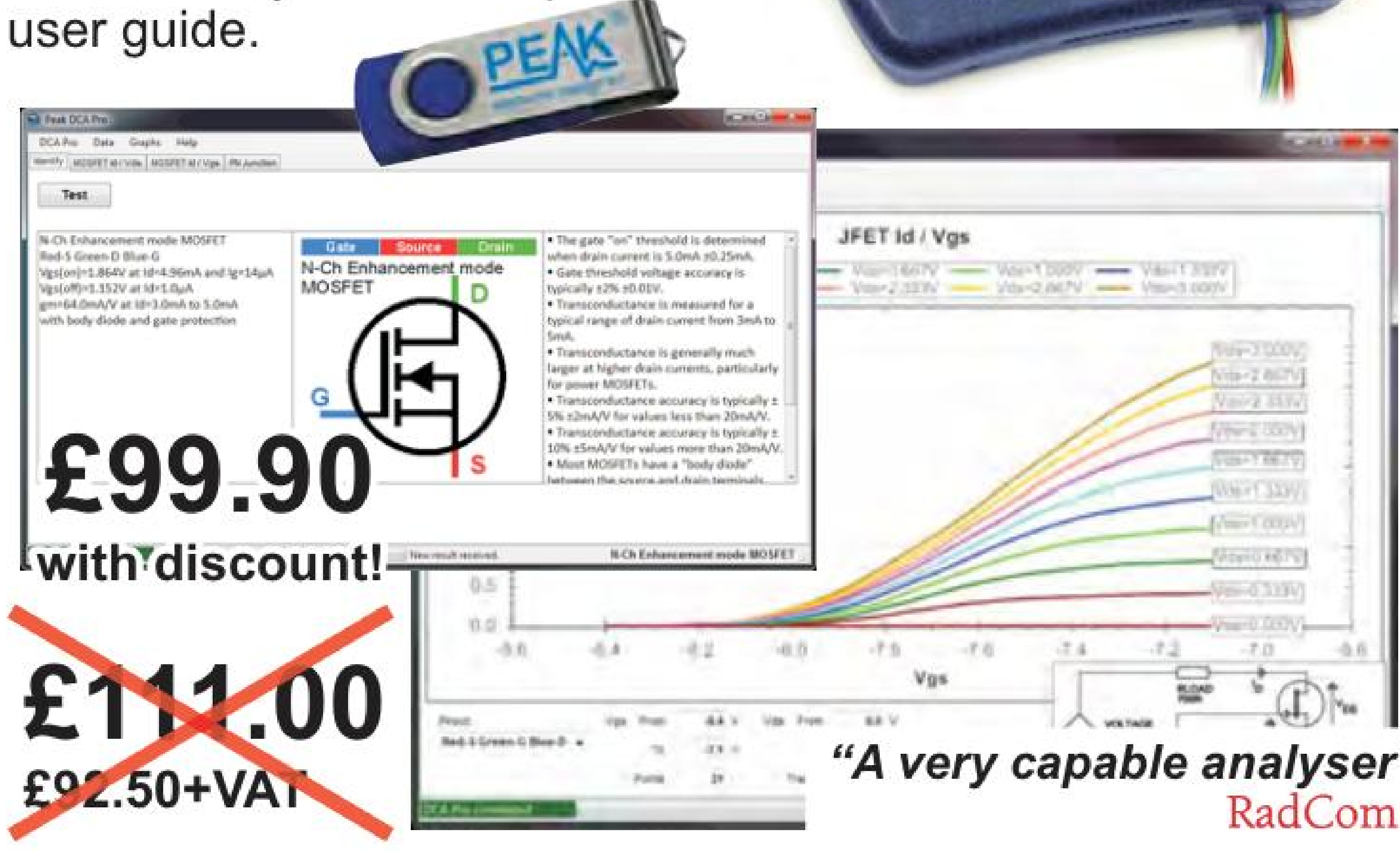
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